SHIP SYNTHESIS MODEL FOR COAST GUARD CUTTERS

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by

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ABSTRACT

Ship Synthesis Model for Coast Guard Cutters
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In order to determine the optimum design of a Coast Guard cutter, it is necessary to perform a large number of feasibility studies. This is an impossible task if done using hand calculations. A mechanized version of these hand calculations is developed which will permit the calculations to be performed by a digital computer. The final program listing is given together with the development of the empirical relations used.

The program is applicable to search and rescue and patrol type cutters with lengths between 150 and 400 feet. Twin screw propulsion is assumed.

A check on the accuracy of the program is made using three U.S. Coast Guard cutters now in service and the U.S. Navy's Patrol Frigate design. The program is found to be much more accurate than existing programs when applied to Coast Guard vessels. The program predicts the full load displacement within four percent for the Coast Guard designs tried.

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CHAPTER I

INTRODUCTION

Although digital computers have been used by engineers for more than twenty years, their potential as design aids is only beginning to be realized. Naval architects made use of computers soon after they became available for solving specific algorithms such as displacement sheet calculations and speed-power estimates. Such algorithms are beneficial in the preliminary and later design stages. However, with the growth of systems engineering in ship design, more emphasis is being placed on the conceptual or earliest phase of a design. At this stage of the design, the computer can be used more effectively than at any other stage.

Because of the complexity of the naval architectural calculations involved in later design stages, the principle characteristics of a ship must be chosen early in the design. The output of the conceptual design phase is this set of characteristics. Without the use of a computer, the best that can be done is to develop a feasible set of characteristics when a optimum set is desired. Systems engineering is placing more emphasis on obtaining this optimum.

To choose an optimum or near optimum set of characteristics, a great many feasibility studies are required. It

is impossible to do more than a few feasibility studies without the aid of computerized models because of the time required. At this early stage, the ship must be designed as a whole. This precludes dividing the work into a number of parallel paths with several people working simultaneously on a single feasibility study. Each study is essentially a one man job.

With hand calculations a good engineer can perform about one feasibility study per day. As a result, great reliance must be placed on the designers intuition. In the past this has led to series of designs which may or may not have been optimum. Each new design was a slight perturbation of a previous successful design. While this procedure produces satisfactory designs, bad features tend to be duplicated and few new features are added. The engineer was not really at fault because no tool was available to perform all the calculations necessary to obtain an optimum design.

Computers permit the mechanization of these hand calculations. The software required will be referred to here as a ship synthesis model. The model aids the designer by freeing him from the routine calculations which take up most of his time during the early phases of design. The algorithms referred to previously also free the designer from tedious calculations.

What makes a ship synthesis model different is that it goes beyond merely reducing the time and effort required

to do calculations previously done by hand. Using the model, hundreds or even thousands of feasibility studies can be made. While this still does not guarantee that the optimum solution is obtained, the engineer will have much more confidence in his design than he would if only a few feasibility studies had been made. The designer is free to concentrate on the more important aspects of the early stages of ship design such as systems level tradeoff decisions. These include hull form, speed, endurance and payload options among others. These aspects were seldom considered in detail before the advent of ship synthesis models.

Equally important is the fact that computers permit a consistency among feasibility studies. With several people doing independent feasibility studies or even with a single person doing them all, it is difficult to insure that the same assumptions will be made for each study and that no bias is applied. The model guarantees consistency. And consistency is important because without it two feasibility studies can not be compared and an optimum solution is difficult to select.

Several models have been available for a number of years and have proven their value. The U.S. Navy's destroyer model, DD07(1)*, on which the program developed in this thesis is patterned, was started in the 1960's

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* Numbers in parenthesis refer to References at the end of this thesis

and updating work has been continuing since then. This was the first true "systems" model. Models also have been developed which attempt to model all surface ship types with a single program. For accurate results, each different ship type really requires its own model.

In addition to the destroyer model, the U.S. Navy has developed individual synthesis models for aircraft carriers, underway replenishment ships, submarines, hydrofoils, and several other ship types. The U.S. Coast Guard presently has no model which gives good results for cutters. The destroyer model, DD07, does not apply to ships as short as 150 feet in length which is one Coast Guard requirement. Some all inclusive models have been tried but with poor success, with predictions of displacement as much as 30 percent off when data on existing designs is inputed.

The program, which will be referred to as the cutter model, developed in this thesis is an attempt to satisfy the Coast Guard's need. The cutter model applies to search and rescue and patrol type cutters with lengths between 150 and 400 feet. It is not applicable to buoy tenders, tugs or ice breakers. An effort has been started by the Coast Guard to develop a model for buoy tenders and tugs but this work is not yet complete.

Even in the early stages of design where the synthesis models are of use, a great many calculations are required to prove the feasibility of a ship design. This has led designers to employ a type of regression analysis where

data from existing ships is scaled up or down in order to estimate values for a new design. This estimation procedure is employed in ship synthesis models also. More detailed calculations could be made but at the cost of greatly increased computer time since a large number of feasibility studies will be run.

The shortcut estimating techniques employed place more emphasis on the relative accuracy among studies rather than on the absolute accuracy of the result. Because of this, all estimating relationships in the model must show the dependence of the result on all significant input variables. At present, this is an impossible task because not enough is known about this dependence. As models become more widely used much development work will have to be done in this area. An estimate of the variation with the most significant input variable is the best that can be done at present.

Because the estimating relationships are rather crude, estimates are only made at the ship system level. Ship system level information consists of such elements as total outfit weight, total volume required for machinery and required electrical load for ventilation. Although total arrangements area is computed, no attempt is made to perform an arrangement of spaces or to compute trim. The engineer usually has sufficient flexibility in these areas to arrive at a feasible design if sufficient space is available.

One problem in developing a model for Coast Guard cutters is that there are few designs available from which to obtain data. This causes difficulty in determining rational scaling laws. In many cases the use of naval architectural principles indicates the correct scaling procedure. In other cases all that can be done is to search for the most logical correlation.

The design produced by a synthesis model should be tailored to meet the conditions required of a feasible solution. First there must be a balance between weight and displacement. Second, internal space available must equal internal space required. This requirement is becoming very important as most Coast Guard vessels are volume rather than weight limited. Third, the energy available must equal the energy required. This includes both propulsion and electrical power requirements. Finally, the distribution of weight and volume must be such as to satisfy design criteria for transverse stability, girder strength and sea keeping. There are also other requirements implicit in the solution such as hull type, material of construction and space requirements.

In general, the inputs required for a ship synthesis model are a description of the "payload" to be carried, a statement of vehicle mobility performance and a selection of options to be used. The payload description must be more detailed than a simple weight breakdown. The relative vertical centers of gravity, area requirements, electrical

power requirements and cost must also be given. Payload for the cutter model also includes people, and thus the size of the crew is an input. The description of vehicle mobility performance includes both maximum calm water speed and endurance speed and range requirements. Options include length, C_p, C_x,* as well as machinery type and margins. There is also an option in the cutter model to input the maximum sustained horsepower, in which case the program will calculate the maximum sustained speed. A full description of the program inputs for the cutter model is contained in Chapter III (Main Program Description) and in Appendix A.

The output generated by the model must be sufficient to demonstrate the feasibility of the design. Wherever possible, the output should permit the designer to verify the feasibility without doing additional calculations. On a few of the studies run and in particular on the design selected, the design team will have to lay out a rough arrangements drawing to verify that sufficient space is available. Sufficient information should be given in the output to permit this to be done easily.

The output generated should also allow the designer to rapidly determine the design that best satisfies his optimization criterion. This criterion usually takes the form of a total acquisition cost or life cycle cost.

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*The definition of coefficients and dimensions used in this thesis may be found in Reference (3).

Predictions of acquisition cost are often included in a ship synthesis model.

Finally, the output should provide a basis for beginning the preliminary design phase. Generally the preliminary phase is handled by a number of design teams working in parallel. The output produced must provide information to initialize each of these parallel developments.

Sample output listings for the cutter model are given in Appendix B.

It is important to emphasize that the cutter model produces a feasible solution only and not an optimum solution. An optimum solution implies that the best of a very large number of feasible ships has been chosen. It is felt that the design process works more efficiently if the designer acts as a guide for the computer rather than having the computer do the entire optimization on a single run. In this way, many unnecessary designs can avoided in areas where designs are less attractive than others already tried. Such a process takes more real time but less computer time. It also gives the designer a much better feel for the sensitivity of the optimum to changes in characteristics.

The remainder of this thesis is arranged as follows:

Chapter II gives an overview of the cutter model and explains the major options.

Chapter III goes into detail on each of the subroutines in the model and explains the derivation of all

of the empirical formulas used. This chapter may be skipped by anyone not interested in the details of the program.

Chapter IV gives an evaluation of the model including test runs made using existing ships.

Chapter V contains recommendations and conclusions.

Appendices A and B contain input and output formats respectively.

Appendix C is a listing of the program.

The remaining appendices give background information used in this work.

It is recommended that at least Chapters I, II, IV, V and Appendix A be read before attempting to use the program. Chapter III is aimed primarily at the person who wishes to modify the program. However, the important aspects of each subroutine are covered in the introduction to each of the subsections of Chapter III.

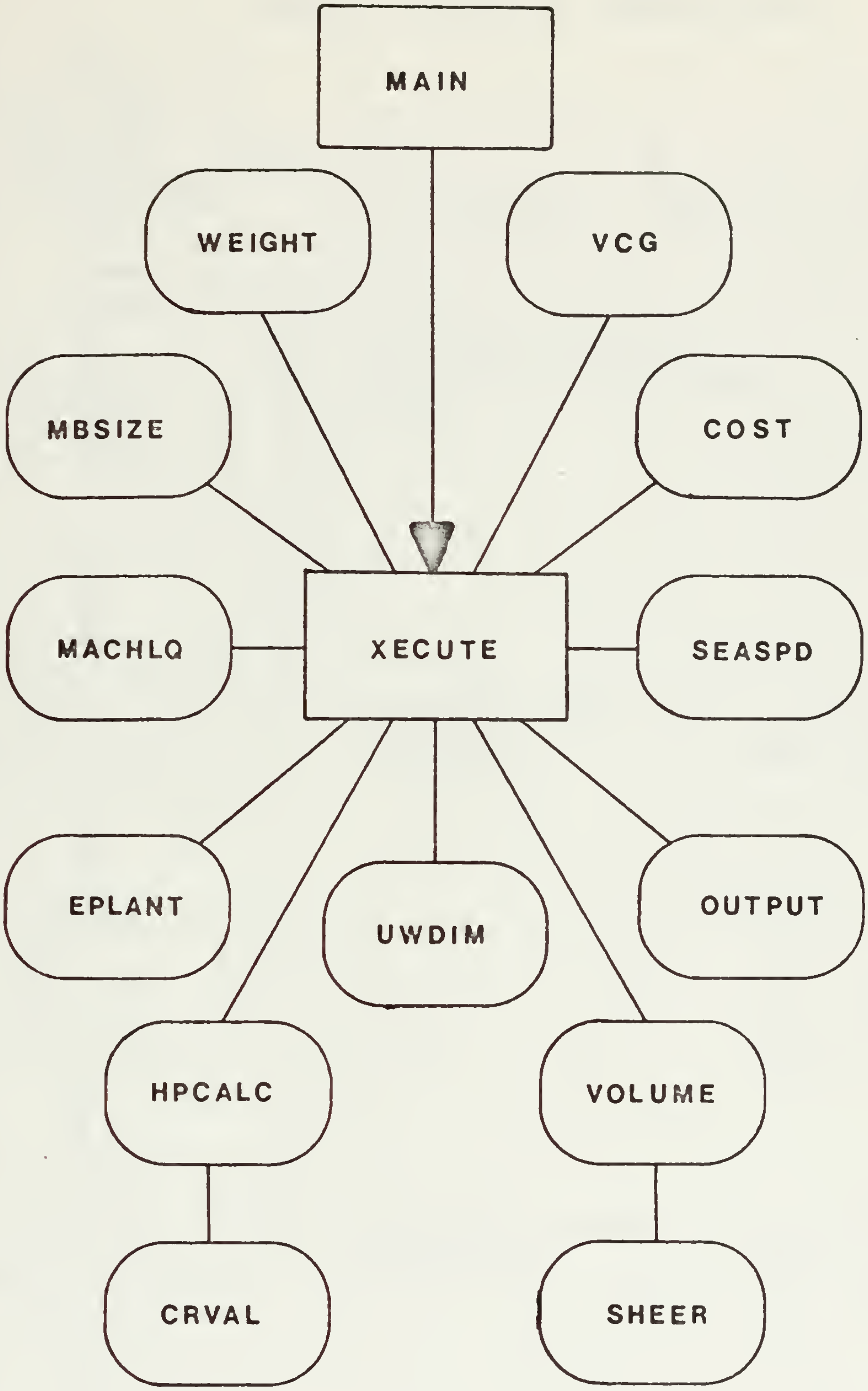
CHAPTER II

GENERAL PROGRAM DESCRIPTION

This chapter gives an overall description of the solution method used by the cutter model but does not discuss the detailed calculations. The detailed calculations are explained in Chapter III. This chapter should also serve as a guide to understanding how each subroutine discussed in Chapter III fits into the total program.

The organization of the computer program can be viewed in two different ways. The first is the program control organization which is shown in Figure 1. Subroutine XECUTE controls the entire solution of each feasibility study case. Control is returned to the main program only when data for a new case is required. Subroutine XECUTE calls other subroutines as needed and gradually fills all the data storage locations needed for output. This subroutine also controls the iteration loops for weight and vertical center of gravity.

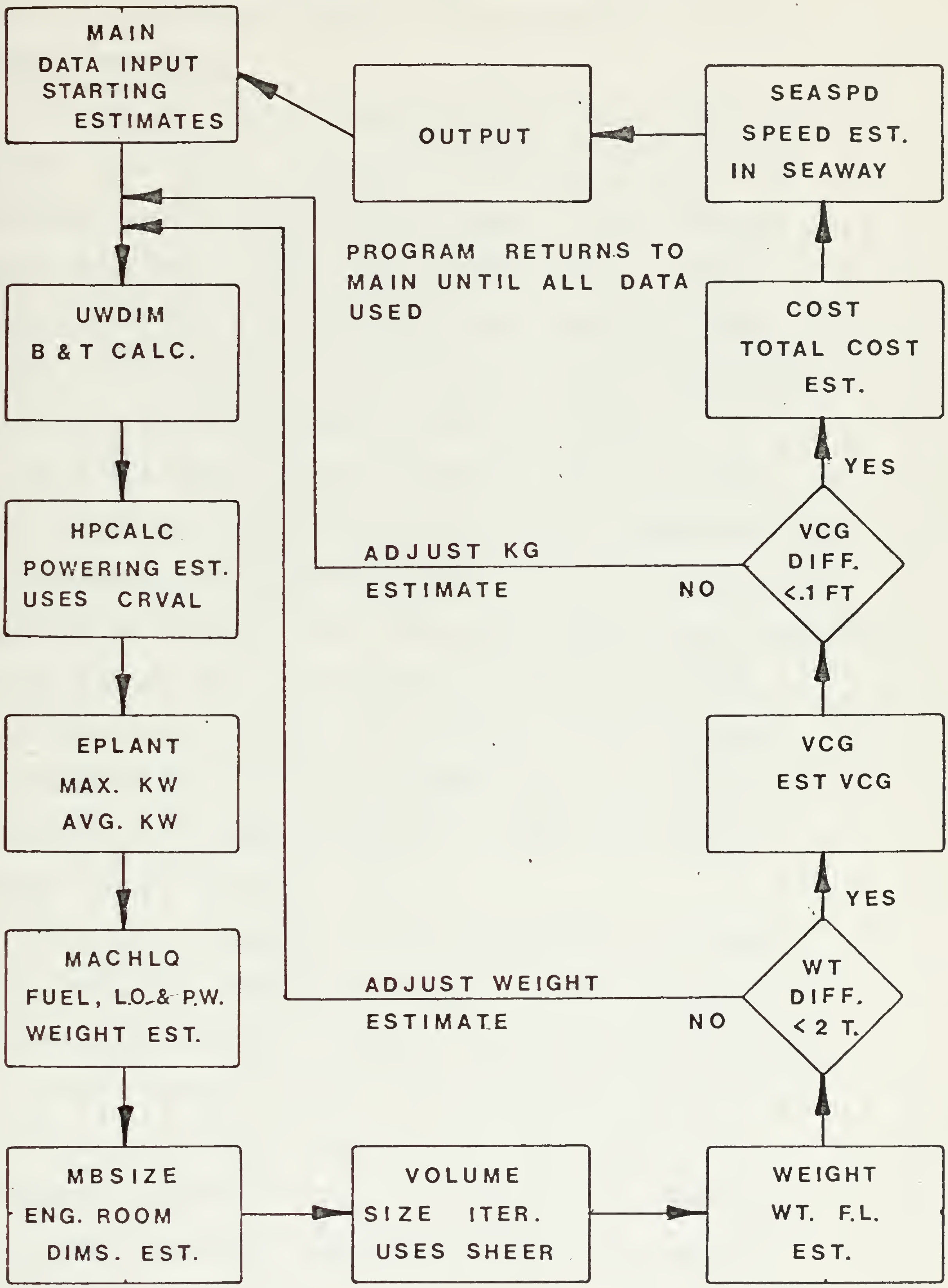
The logical organization of the program is shown schematically in Figure 2. This is an easier organization scheme to follow and shows more clearly how the program solves each input case. It will be noted that subroutine XECUTE has not been shown in Figure 2. As explained above, XECUTE merely guides the computer around the



PROGRAM CONTROL ORGANIZATION

Figure 1

Figure 2
LOGICAL PROGRAM ORGANIZATION



logical organization chart. Error messages are also printed by subroutine XECUTE if any constraint of the model is violated.

The program begins with data input in the MAIN program. The primary purpose of the MAIN program is to read data cards and all input is done in this routine. Some bookkeeping is also done in MAIN such as summing payload weights and costs. The final purpose of this routine is to estimate initial values of vertical center of gravity, KG; displacement, and cubic number.

Once all data for one feasibility study has been read by MAIN and the initial values of KG, displacement and cubic number have been determined, control is transferred to subroutine XECUTE. This subroutine directs the execution of the program until a solution is obtained or until a constraint is violated. When either of these occur control reverts to the MAIN program where data for the next feasibility study is read. If there is no more data the program stops.

The first subroutine called by XECUTE is an under-water dimensions subroutine, UWDIM. Subroutine UWDIM uses the input values of length, free surface correction, C_p, C_x and GM/Beam as well as the estimated KG and displacement to calculate the required beam, draft and waterplane coefficient, C_{wp}. To the level of accuracy of this program these completely determine the under-water shape of the hull.

Two options are available with regard to speed and power calculations. Under the first option the maximum sustained speed of the vessel is input. If this option is specified, XECUTE calls subroutine HPCALC which, together with subroutine CRVAL, estimates the horsepower required to maintain the maximum sustained speed.

Option two allows the user to specify the maximum sustained horsepower. In this case the program will compute the maximum sustained speed. Subroutine HPCALC has been written to take speed as an input and return a value of horsepower. Therefore, an iterative procedure is required if this second option is used. Control of this iteration takes place in subroutine XECUTE.

Regardless of which of the above options is used the endurance speed is input. Subroutine HPCALC is called to determine the power required at endurance speed.

A Taylor Standard Series horsepower estimate is used in subroutine HPCALC. Stored values of C_r are used. The purpose of subroutine CRVAL is to choose the correct C_r value from a stored array. Reference (7) explains this method for estimating horsepower.

The electrical power routine, EPLANT, is the next one called. This routine determines the maximum electrical load at sea, the average electrical load and sizes the generators. The average load is needed for estimating generator fuel consumption. The input electrical loads along with crew size and cubic number are used in this

routine.

The weight of fuel, lubricating oil and potable water is next calculated in subroutine MACHLQ. The endurance range given as input together with crew size and the endurance power calculated earlier are used by this routine. Lub oil requirements are either input, in the case where horsepower is specified, or are estimated based on specified machinery type. Potable water requirements depend entirely on the crew size. If make-up feed water is required it should be specified as a cargo load item. The specific fuel consumption is either input, in the case where horsepower is specified, or is estimated based on machinery type and horsepower.

Subroutine MBSIZE is next called if the sustained speed is specified. This routine estimates the machinery box length and minimum depth. If the horsepower input option is specified these dimensions are input.

The next subroutine is one of the most important in the program. Subroutine VOLUME determines both the sheer line and the deckhouse volume. These complete the definition of internal volume and arrangements area since the underwater volume has been determined in subroutine UWDIM. Because most ships for which this program applies are volume rather than weight limited, it is important to insure that there is sufficient space for all ship functions and equipment which must be installed.

The volume is divided into three categories. First,

there is the engine room. The dimensions for the engine room have been estimated earlier. Second is tankage volume and finally arrangements volume. Arrangements volume is more useful if converted to an arrangements area.

As a first step in determining the space available in each of these categories, the sheer line must be determined. Subroutine VOLUME calls subroutine SHEER to determine an acceptable sheer line. The sheer line must meet several criteria including adequate freeboard forward and aft, adequate depth amidships for the engine room and for adequate strength and an acceptable sheer line curvature.

With the sheer line fixed, the total volume of the hull is estimated. The volume of the engine room is also estimated and then subtracted from the total volume. Next, an estimate is made of the fraction of the remaining volume which can be used only for tankage because it is unsuitable for use as arrangements volume.

A required tankage volume is then estimated based on the weights of fuel, lub oil, potable water and aircraft fuel. This required tankage volume is compared to the volume which must be used for tankage. The larger of the two is subtracted from the hull volume that remains. The remaining hull area is available for use as arrangements volume. This volume is converted into an arrangements area.

A required arrangements area is computed based on

empirical data from past designs and on input area values. By adjusting the size of the superstructure or by adding a raised deck, the available arrangements area can usually be made to equal the required arrangements area. If too large a deckhouse is required or if a raised deck longer than the length of the ship is needed, an error message is generated and a new input case is tried.

Once the volume of the hull has been determined, the weight of all the light ship weight groups and of the load items can be calculated. This is done in subroutine WEIGHT. Although many of the items calculated by this routine are later printed as output, the variable of immediate importance is the full load weight, WFULLD. This value is compared with the initial guess of displacement. If there is a difference of greater than 2 tons between the two, a new estimate of displacement is made and the program returns to subroutine UWDIM for a new estimate of dimensions. Once a balance between WFULLD and displacement is achieved the program proceeds to the estimation of vertical center of gravity.

Subroutine VCG makes this estimate. Most centers are taken as a fraction of the average depth of the hull or of the amidships depth. The estimated vcg is compared to the initial guess and a new KG estimate is made if there is no agreement within a tenth of a foot. Once a balance is obtained, the program proceeds to a cost estimate.

The lead ship cost is estimated using a Coast Guard cost estimating procedure known as "Flanagan's Method".[6] This procedure has been programmed as subroutine COST.

An estimate of the speed the vessel will be able to sustain in the North Atlantic Ocean is made in subroutine SEASPD. This routine is based on work done at the Naval Ship Engineering Center as reported in References (4) and (5).

Finally, subroutine OUTPUT is called. The purpose of this routine is to print the values determined by the other routines. The input data is also printed so that a compact record of the feasibility study is produced. After the output is printed, the program returns to the MAIN program to read more data and start a new case.

This concludes the general description of the program. A much more detailed description is given in Chapter III. The reader who is not interested in the details of the program can skip Chapter III with no loss of continuity.

CHAPTER III

DETAILED DESCRIPTION OF THE PROGRAM

3.1 Introduction

This chapter is composed of sixteen sections including this introduction. The other fifteen sections each explain in detail one subroutine of the cutter model. For the location of these subroutines in the overall program refer to Figure 2, Logical Program Organization.

An attempt has been made to keep each section in the same format. A brief description of the routine will be given first followed by a list of required inputs. Statements will then be explained one by one. A list of the outputs produced by the subroutine will be given next. Finally, a nomenclature list will be given. The nomenclature list applies only to the subroutine being considered. In some cases the same variable will have different names in different subroutines.

In both the input and output listings a code is employed to indicate whether the variable is transferred by a labeled common statement, LC(AA), or as a subroutine call dummy argument, SCDA. The letters in parenthesis after the labeled common code indicate which labeled common was used to transfer the argument.

3.2 MAIN Program

3.2.1 Introduction

The MAIN subroutine performs several functions. First and most important is the reading of all input data used by the model. Each feasibility study case starts with the reading of one or more data cards by the MAIN program. The actual execution of each case is controlled by subroutine XECUTE. This routine is discussed in Section 3.3. However, once execution on a case is complete, control is returned to the MAIN subroutine. A check is then made to see if there is more input data. If not the MAIN subroutine directs the computer to stop.

Several bookkeeping tasks are performed in this subroutine also. These include such jobs as adding together the deck area and electrical load requirements of the individual payload items. The final function performed is the setting of initial values for displacement, KG and cubic number. These values are used for the first iteration and are then replaced by better estimates.

3.2.2 Inputs

Block Data subroutines have not been used in this model. As a result there are no variables with assigned values at the beginning of the MAIN program. All of the variables required are read from data cards or assigned values in the routine.

A flow chart for this routine is given in Figures

3a and 3b. A listing of the program is given in Appendix C. The nomenclature list at the end of this section gives a description of each variable name used.

3.2.3 Statement Descriptions

A line by line discussion of the program statements follows. The REAL and COMMON statements have not been listed but may be found in Appendix C.

REAL Statements - An explicit type definition has been employed so that the variable names will be more descriptive of their actual meanings.

COMMON Statements - Because a great many variables are required to define each case, COMMON statements have been used to transfer values between subroutines. This also saves computer storage space. All COMMON statements used are labeled common.

C_r array input:

```
      READ(8,120) CR1
  120 FORMAT(16F5.0)
      READ(8,121) CR2
  121 FORMAT(9F5.0)
      READ(8,122) CR3
  122 FORMAT(6F5.0)
```

The three arrays which contain the Taylor's Standard Series C_r values are read only once at the beginning of the program.

INDEX input:

```
    2 READ(8,124) INDEX
  124 FORMAT(I1)
```

The variable named INDEX has two functions. First, as described below, it tells the program when to stop.

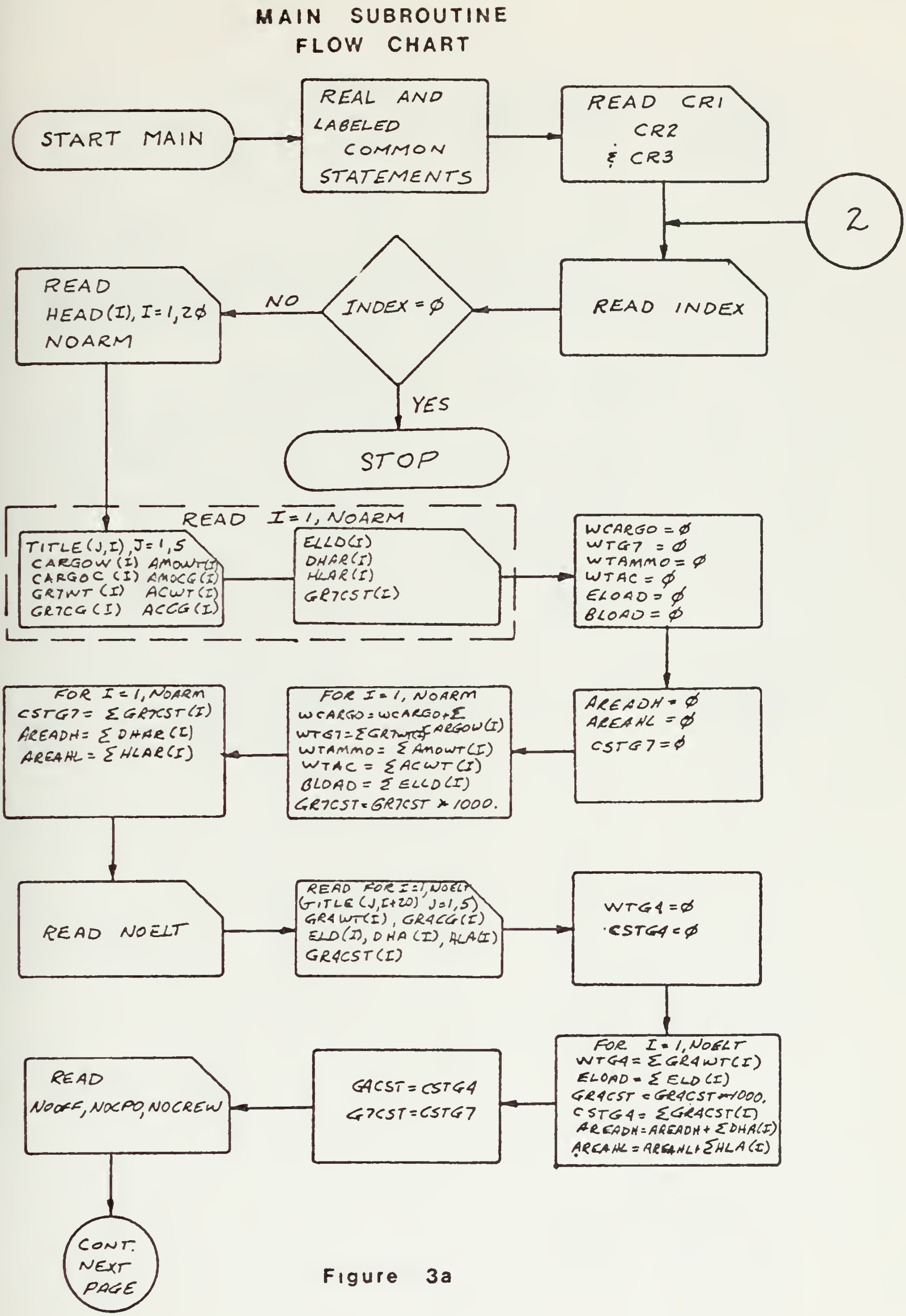

MAIN SUBROUTINE
FLOW CHART
START MAIN
REAL AND LABELED COMMON STATEMENTS
READ CR1 CR2 & CR3
2
READ INDEX
INDEX = Ø
NO
YES
STOP
READ HEAD(I), I=1,2Ø NOARM
READ I=1, NOARM
TITLE(J,I), J=1,5 CARGOW (I) AMOWT(I) CARGOC (I) AMOCG(I) GR7WT (I) ACWT(I) GR7CG (I) ACCG (I)
ELLD(I) DHAR(I) HLAR(I) GR7CST(I)
WCARGO = Ø WTG7 = Ø WTAMMO = Ø WTAC = Ø ELOAD = Ø BLOAD = Ø
AREADH = Ø AREAHL = Ø CSTG7 = Ø
FOR I=1, NOARM WCARGO = WCARGO + Σ CARGOW(I) WTG7 = Σ GR7WT WTAMMO = Σ AMOWT(I) WTAC = Σ ACWT (I) BLOAD = Σ ELLD (I) GR7CST = GR7CST * 1000.
FOR I=1, NOARM CSTG7 = Σ GR7CST (I) AREADH = Σ DHAR (I) AREAHL = Σ HLAR(I)
READ NOELT
READ FOR I=1, NOELT (TITLE (J,I+20) J=1,5) GR4WT(I), GR4CG(I) ELD(I), DHA (I), HLA(I) GR4CST (I)
WTG4 = Ø CSTG4 = Ø
FOR I=1, NOELT WTG4 = Σ GR4WT(I) ELOAD = Σ ELD (I) GR4CST = GR4CST * 1000. CSTG4 = Σ GR4CST(I) AREADH = AREADH + Σ DHA(I) AREAHL = AREAHL + Σ HLA (I)
G4CST = CSTG4 G7CST = CSTG7
READ NOOFF, NOCPO, NOCREW
CONT. NEXT PAGE

Figure 3a

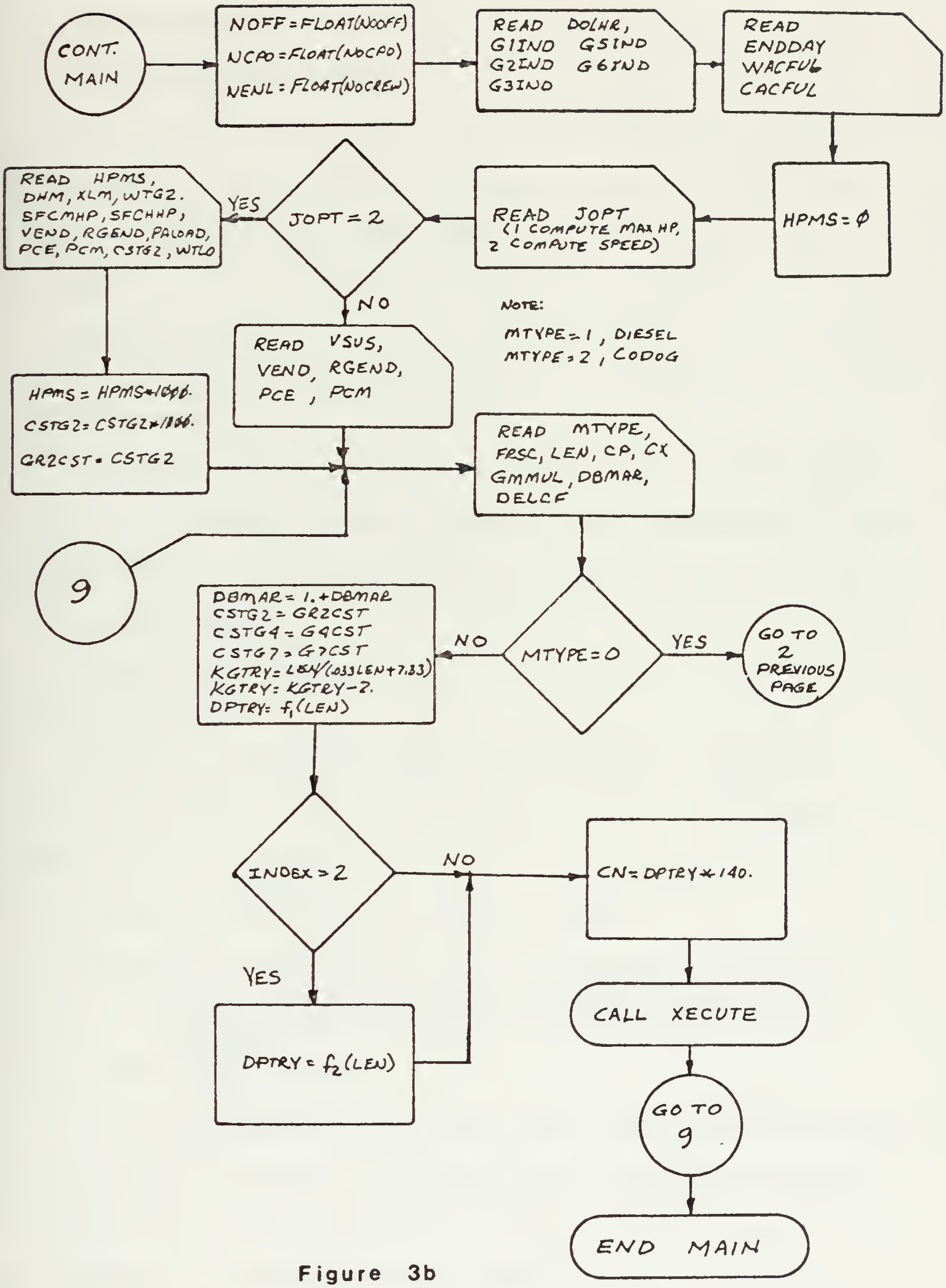

CONT. MAIN
NOFF=FLOAT(NOOFF)
NCPO=FLOAT(NOCPO)
NENL=FLOAT(NOCREW)
READ DOLHR, G1IND G5IND G2IND G6IND G3IND
READ ENDDAY WACFUL CACFUL
HPMS=Ø
READ JOPT (1 COMPUTE MAX HP, 2 COMPUTE SPEED)
JOPT=2
YES
NO
READ HPMS, DHM, XLM, WTG2. SFCMHP, SFCHHP, VEND, RGEND, PALOAD, PCE, PCM, CSTG2, WTLO
HPMS=HPMS*1000.
CSTG2=CSTG2*1000.
GR2CST=CSTG2
READ VSUS, VEND, RGEND, PCE, PCM
NOTE:
MTYPE=1, DIESEL
MTYPE=2, CODOG
READ MTYPE, FRSC, LEN, CP, CX GMMUL, DBMAR, DELCF
9
MTYPE=0
NO
YES
GO TO 2 PREVIOUS PAGE
DBMAR=1.+DBMAR
CSTG2=GR2CST
CSTG4=G4CST
CSTG7=G7CST
KGTRY=LEN/(.033LEN+7.33)
KGTRY=KGTRY-2.
DPTRY=f1(LEN)
INDEX=2
NO
YES
CN=DPTRY*140.
DPTRY=f2(LEN)
CALL XECUTE
GO TO 9
END MAIN

Figure 3b

It is also used to discern between full hull ships and fine hull ships for the initial guess of displacement.

Stop execution:

```
IF(INDEX.EQ.0) STOP
```

This is the only place where the program is directed to stop execution. However, if a data card is left out, the program will stop when there is no more data cards to read.

Heading input:

```
     READ(8,123)(HEAD(I),I=1,20)
 123 FORMAT(20A4)
```

Variable HEAD contains any alphanumeric information. It will be printed without change at the beginning of the output for all test cases using the data which follows.

NOARM input:

```
     READ(8,100) NOARM
 100 FORMAT(I2)
```

NOARM is the total number of armament, aircraft and cargo payload data cards which follow. A maximum value of 20 is allowed.

Armament, aircraft and cargo input:

```
     READ(8,101)((TITLE(J,I),J=1,5),CARGOW(I),CARGOC(I),
          GR7WT(I),GR7CG(I),AMOWT(I),AMOCG(I),ACWT(I),
          ACCG(I),ELLD(I),DHAR(I),HLAR(I),GR7CST(I),I=
          1,NOARM)
 101 FORMAT(5A4,12F5.0)
```

Up to 20 armament, aircraft and cargo payload description cards are allowed. The data may be lumped together and appear on only one card or it may be broken up in any way desired. However, if a weight is given, a vertical

center of gravity must also be given on the same card immediately following the weight. The first 20 spaces on each card are reserved for an alphanumeric description of the payload items on the card. This is used as a line title in the output listing. Of the four weight categories on the card only the group 7 weights are included in the light ship weight. From a calculation standpoint it is unimportant whether ammunition or aircraft are listed separately or considered cargo. However, if they are listed as cargo they will be classified incorrectly in the output listing.

All vertical center of gravity values should be inputed as a multiplier of the hull depth at amidships. This number is easier to estimate than the actual center in feet. As an example, if a payload item has its center 10 feet above the baseline and the depth at amidships is 20 feet the value entered is 0.5.

The deckhouse area should include only the area that is required to be in the deckhouse. If the area could be in either the deckhouse or the hull it should be included in the hull area. The group 7 cost should include only the cost of materials and should be estimated for the time when the ship will be built. Because of format limitations the value input should be the true cost divided by 1000. All weights are in tons, all areas in square feet, all electrical loads in KW and all costs in dollars. This applies to all the input items.

Summing the payload data:

```
      WCARGO=0.
      WTG7=0.
      WTAMMO=0.
      WTAC=0.
      ELOAD=0.
      BLOAD=0.
      AREADH=0.
      AREAHL=0.
      CSTG7=0.
      DO 10 I=1,NOARM
      WCARGO=WCARGO+CARGOW(I)
      WTG7=WTG7+GR7WT(I)
      WTAMMO=WTAMMO+AMOWT(I)
      WTAC=WTAC+ACWT(I)
      BLOAD=BLOAD+ELLD(I)
      GR7CST(I)=GR7CST(I)*1000.
      CSTG7=CSTG7+GR7CST(I)
      AREADH=AREADH+DHAR(I)
   10 AREAHL=AREAHL+HLAR(I)
```

Only the totals of the payload items entered are needed for calculations. These totals are computed in the above statements.

NOELT input:

```
      READ(8,102) NOELT
  102 FORMAT(I2)
```

This variable serves the same purpose as NOARM. A maximum value of 20 is allowed.

Electronics input:

```
      READ(8,103)((TITLE(J,I+20),J=1,5),GR4WT(I),GR4CG(I),
     1     ELD(I),DHA(I),HLA(I),GR4CST(I),I=1,NOELT)
  103 FORMAT(5A4,6F5.0)
```

The comments made about armament input also apply here. Group 4 weights are included in the light ship weight. All items normally in group 4 should be included since no allowance is made in the program for navigation equipment.

Summing electronics input data:

```
      WTG4=0.
      CSTG4=0.
      DO 11 I=1,NOELT
      WTG4=WTG4+GR4WT(I)
      ELOAD=ELOAD+ELD(I)
      GR4CST(I)=GR4CST(I)*1000.
      CSTG4=CSTG4+GR4CST(I)
      AREADH=AREADH+DHA(I)
   11 AREAHL=AREAHL+HLA(I)
```

The comments about summing armament data also apply here. Note that the area in the hull and deckhouse is a combined total of all the payload inputs, both electronic and armament.

Storing initial costs:

```
      G4CST=CSTG4
      G7CST=CSTG7
```

Because the value of variables CSTG4 and CSTG7 are modified during the execution of the program, a record is required of their initial values so that they will be available if another test case using the same payload is run.

Manning input:

```
      READ(8,104) NOOFF,NOCPO,NOCREW
  104 FORMAT(3I5)
      NOFF=FLOAT(NOOFF)
      NCPO=FLOAT(NOCPO)
      NENL=FLOAT(NOCREW)
```

The number of officers, chief petty officers and crew members are input and then converted to real values so that they can be used in non-integer equations.

Cost indices input:

```
      READ(8,110)DOLHR,G1IND,G2IND,G3IND,G5IND,G6IND
  110 FORMAT(6F5.0)
```

The labor rate for the year the ship will be built must be estimated as must the inflation corrections for material costs. These corrections are for the period from 1959 to the year the ship is to be built. Section 3.14 gives some guidance as to the values to use. The indices can also include special material costs such as making the hull out of HY-80 steel instead of mild steel.

Military mission consumables input:

```
    READ(8,105)ENDDAY,WACFUL,CACFUL
105 FORMAT(3F5.0)
```

The number of endurance days for dry provisions should be given. All other endurance days are taken as a suitable fraction of this number. The weight and center of gravity of aircraft fuel must also be given.

```
    HPMS=0.
```

This is done so that there is no difficulty in calling subroutine XECUTE.

JOPT input:

```
    READ(8,106) JOPT
106 FORMAT(I2)
    IF(JOPT.EQ.2)GOTO 1
```

This variable denotes the option to be used in entering vehicle performance data. If JOPT equals 1, the maximum sustained speed is input. If JOPT equals 2, the maximum sustained horsepower and machinery characteristics are input.

Vehicle performance input for JOPT equal 1:

```
    READ(8,107)VSUS,VEND,RGEND,PCE,PCM
107 FORMAT(2F5.0,F10.0,2F5.0)
    GOTO 9
```

The maximum sustained speed is input along with the endurance speed and endurance range. The propulsive coefficients at the endurance speed and at maximum speed must also be given.

Vehicle performance input for JOPT equal 2:

```
  1 READ(8,108)HPMS,DHM,XLM,WTG2,SFCMHP,SFCHHP,VEND,RGEND,
         PALOAD,PCE,PCM,CSTG2,WTLO
108 FORMAT(7F5.0,F10.0,5F5.0)
    HPMS=HPMS*1000.
    CSTG2=CSTG2*1000.
    GR2CST=CSTG2
```

This option is used primarily when a specific machinery plant is desired. Besides the maximum sustained horsepower, the length and minimum depth of the engine room must be given. The total group 2 weight and specific fuel consumptions at maximum and half power are required. The endurance speed and range must be given as before. Propulsion auxiliaries electrical load and propulsive coefficients at full and endurance speed are required as are the group 2 material cost and lub oil weight.

To fit into the format used, the horsepower and cost values must be divided by 1000. The cost of group 2 must be stored for later use as were the costs of group 4 and group 7.

Options input:

```
  9 READ(8,109)MTYPE,FRSC,LEN,CP,CX,GMMUL,DBMAR,DELCF
109 FORMAT(I5,6F5.0,F10.0)
```

Machinery type must always be specified even if the option of inputing machinery characteristics was used. If machinery information was given, any number except

zero can be used for MTYPE. A value of zero will cause the program to assume the next input value is INDEX. This can be used to return and stop the program or to input a new set of data for another ship. If the machinery particulars have not been specified, MTYPE equals zero has the same effect. However, MTYPE equals 1 will cause the program to assume a diesel plant is to be installed. A value of MTYPE equal to 2 will result in calculations for a CODOG plant. These are the only two machinery types for which estimating relationships have been included in the program. If MTYPE is any other number, the results are unpredictable.

A free surface correction can be specified. This value is interpreted as a rise in the full load KG of the ship in an amount equal to FRSC in feet. A negative value can also be used. In this case FRSC can be interpreted as a lowering of the average KG value built into the program.

The length between perpendiculars is given next. The values for C_p and C_x have the standard naval architectural definitions.[3] GMMUL if the fraction GM/Beam, A value of 0.1 is commonly used. The next variable, DBMAR, is a design and builders margin. This is given as a fraction, i.e., a 10 percent margin is input as 0.1. DELCF is the ΔC_f value used in the calculation of horsepower. A value of 0.0004 is common.

```
IF(MTYPE.EQ.0) GOTO 2
```

One or more option input cards may follow the first. The program will assume that each one is a new input case with all other data the same. To input an entirely new set of data, an option input card with a value of MTYPE equal to zero should be included. No other values need be given on the card. This will cause the next input card to be interpreted as a new value for INDEX.

```
DBMAR=1.+DBMAR
CSTG2=GR2CST
CSTG4=G4CST
CSTG7=G7CST
```

DBMAR is changed to a multiplier for weight and the input costs are reset to their initial values.

Initial KG estimate:

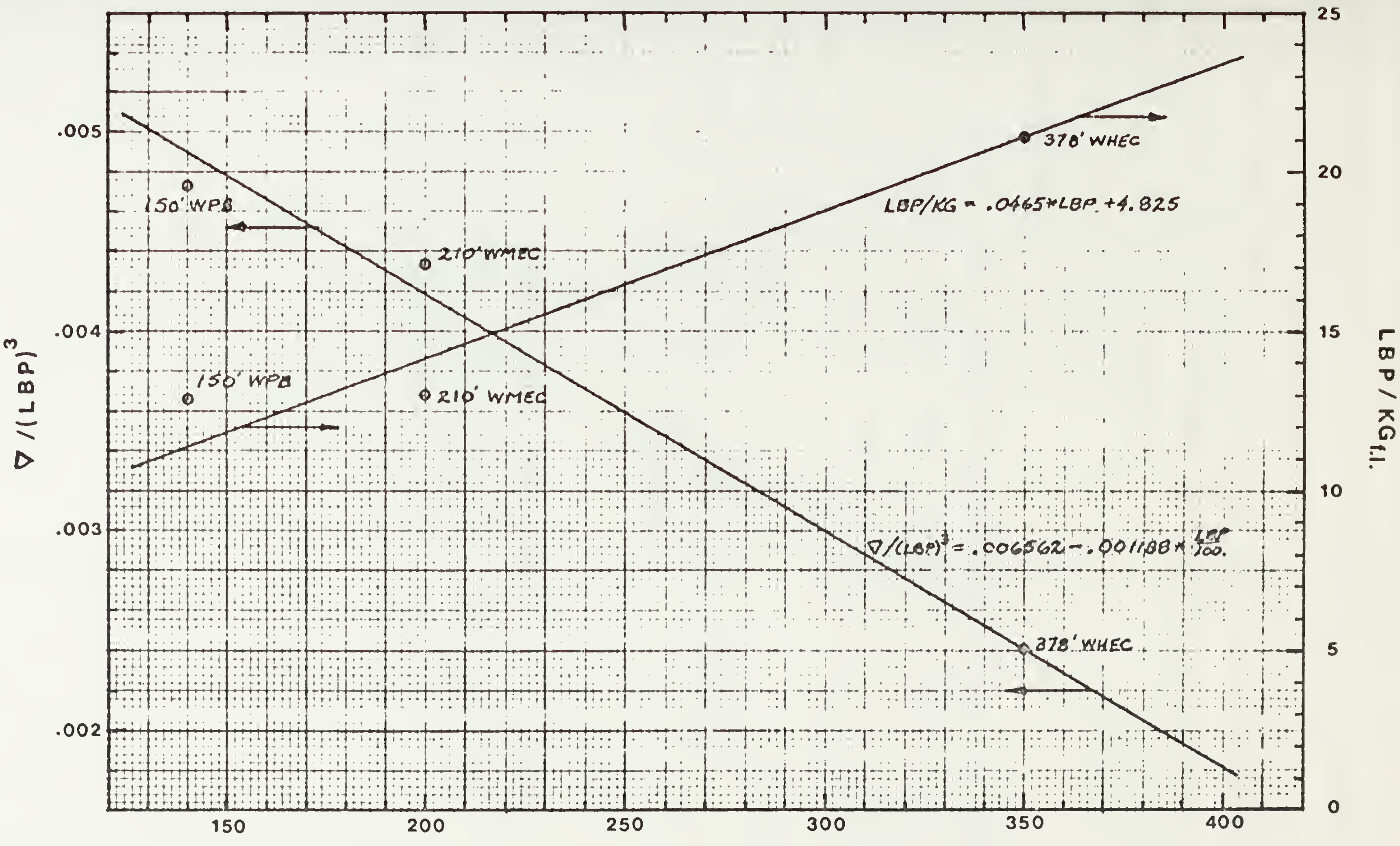
```
KGTRY=LEN/(.0465*LEN+4.825)
KGTRY=KGTRY-2.
```

The initial KG value is estimated based on the values for current Coast Guard vessels. These are shown in Figure 4. Reducing the initial estimate by 2 feet was found to be advantageous. It helps to insure that the first iteration will not exceed the KG constraints of the program.

Initial displacement estimate:

```
DPTRY=(.006562-.001188*LEN/100.)*LEN**3/35.
IF(INDEX.EQ.2)DPTRY=.0025*LEN**3/35.
```

Two initial values of displacement are available. For an INDEX value other than 2 the displacement is taken as that of conventional Coast Guard vessels. This displacement curve is shown on Figure 4. However, if the



.005
.004
.003
.002
∇ /(LBP)³
25
20
15
10
5
0
LBP / KG f.l.
150
200
250
300
350
400
LBP - FT
150' WPB
150' WPB
210' WMEC
210' WMEC
378' WHEC
378' WHEC
LBP/KG = .0465*LBP +4.825
∇/(LBP)³ = .006562 - .001188 * LBP/100.

Figure 4

vessel has a high speed-length ratio, greater than 1.3, it will not be possible to find the horsepower in some cases if the conventional ship curve is used. This is due to the limitations on the C_r arrays. By specifying an INDEX equal to 2 the program assumes a fine form at least for the first iteration.

Cubic number estimate:

```
CN=DPTRY*160
```

An initial cubic number is assumed for use in estmating the electrical load on the first iteration. Values for current Coast Guard vessels range from 140 to 180 times the displacement.

```
CALL XECUTE(HPMS)
```

Control is transferred to subroutine XECUTE to calculate the vessels characteristics.

```
GOTO 9
END
```

The GOTO statement causes the program to loop back and try to read another options input data card. The END statement stops compilation of the routine.

3.2.4 List of Outputs of MAIN Subroutine

ACCG(20)............LC(EE)
ACWT(20)............LC(EE)
AMCCG(20)...........LC(EE)
AMOWT(20)...........LC(EE)
AREADH..............LC(BB)
AREAHL..............LC(BB)
BLOAD...............LC(DD)
CACFUL..............LC(HH)
CARGOC(20)..........LC(EE)
CARGOW(20)..........LC(EE)
CN..................LC(BB)
CP..................LC(GG)
CR1(1152)...........LC(TT)
CR2(972)............LC(TT)
CR3(216)............LC(TT)
CSTG2**.............LC(MM)
CSTG4...............LC(MM)
CSTG7...............LC(MM)
CX..................LC(GG)
DBMAR...............LC(WW)
DELCF...............LC(CC)
DHA(20).............LC(KK)
DHAR(20)............LC(KK)
DHM**...............LC(JJ)
DOLHR...............LC(NN)
DPTRY...............LC(GG)
ELD(20).............LC(KK)
ELLD(20)............LC(KK)
ELOAD...............LC(DD)
ENDDAY..............LC(AA)
FRSC................LC(GG)
G1IND...............LC(NN)
G2IND...............LC(NN)
G3IND...............LC(NN)
G5IND...............LC(NN)
G6IND...............LC(NN)
GMMUL...............LC(GG)
GR4CG(20)...........LC(EE)
GR4CST(20)..........LC(KK)
GR4WT(20)...........LC(EE)
GR7CG(20)...........LC(EE)
GR7CST(20)..........LC(KK)
GR7WT(20)...........LC(EE)
HEAD(20)............LC(FF)
HLA(20).............LC(KK)
HLAR(20)............LC(KK)
HPMS.................SCDA
JOPT................LC(CC)
KGTRY...............LC(GG)
LEN.................LC(BB)
MTYPE...............LC(CC)
NCPO................LC(AA)

List of Outputs of MAIN Subroutine (cont)

NENL...............LC(AA)	VEND..............LC(CC)
NOARM..............LC(FF)	VSUS*.............LC(CC)
NOELT..............LC(FF)	WACFUL............LC(LL)
NOFF...............LC(AA)	WCARGO............LC(LL)
PALOAD**...........LC(DD)	WTAC..............LC(LL)
PCE................LC(CC)	WTAMMO............LC(LL)
PCM................LC(CC)	WTG2**............LC(WW)
RGEND..............LC(CC)	WTG4..............LC(WW)
SFCHHP**...........LC(CC)	WTG7..............LC(WW)
SFCMHP**...........LC(CC)	WTLO**............LC(LL)
TITLE(5,40)........LC(FF)	XLM**.............LC(JJ)

* Output only if JOPT = 1

** Output only if JOPT = 2

3.2.5 Nomenclature List

ACCG(20)	aircraft vcg/D10, D10 = depth amidships
ACWT(20)	aircraft weight, tons
AMOCG(20)	ammunition vcg/D10
AMOWT(20)	ammunition weight, tons
AREADH	total input deckhouse arrangements area, sq ft
AREAHL	total input hull arrangements area, sq ft
AVGKW	average electrical load, KW
B	maximum beam, feet
BLOAD	total armament electrical load, KW
CACFUL	aircraft fuel vcg/D10
CARGOC(20)	cargo vcg/D10
CARGOW(20)	cargo weight, tons
CCARGO	total vcg of cargo inputs, feet
CCST	construction services cost, dollars
CGAC	total vcg of aircraft, feet
CGAMMO	total vcg of ammunition, feet
CGCREW	total vcg of crew, feet
CGFUEL	total vcg of ships fuel, feet
CGLO	total vcg of lub oil, feet
CGPE	total vcg of personal effects, feet
CGPS	total vcg of personnel stores, feet
CN	cubic number, cubic ft
CP	prismatic coefficient
CR1(1152) CR2(972) CR3(216)	C_r arrays for Taylor's Standard Series resistance estimate

Nomenclature List (cont)

CSTG1	total cost of weight group 1, dollars
CSTG2	total cost of weight group 2, dollars
CSTG3	total cost of weight group 3, dollars
CSTG4	total cost of weight group 4, dollars
CSTG5	total cost of weight group 5, dollars
CSTG6	total cost of weight group 6, dollars
CSTG7	total cost of weight group 7, dollars
CWP	waterplane coefficient
CX	midship section coefficient
DAVG	average hull depth, feet
DBMAR	design and builders margin
DCST	design cost, dollars
DELCF	ΔC_f used in resistance calculation
DHA(20)	electronics deckhouse area, sq ft
DHAR(20)	armament deckhouse area, sq ft
DHM	minimum machinery box depth, feet
DHV	deckhouse volume, cu ft
DOLHR	labor rate, dollars/hour
DPTRY	displacement estimate, tons
ELD(20)	electronics electrical load, KW
ELKW	generator rated load, KW
ELLD(20)	armament electrical load, KW
ELOAD	total electronics electrical load, KW
ENCVOL	total volume of hull and deckhouse, cu ft
ENDDAY	number of endurance days for dry provisions
FRSC	free surface correction, feet

Nomenclature List (cont)

G1IND	cost index for weight group 1
G2IND	cost index for weight group 2
G3IND	cost index for weight group 3
G4CST	total material cost weight group 4, dollars
G5IND	cost index for weight group 5
G6IND	cost index for weight group 6
G7CST	total material cost weight group 7, dollars
GMMUL	GM/Beam ratio
GR2CST	total material cost weight group 2, dollars
GR4CG(20)	group 4 vcg/D10
GR4CST(20)	material cost weight group 4, dollars
GR4WT(20)	group 4 weight, tons
GR7CG(20)	group 7 vcg/D10
GR7CST(20)	material cost weight group 7, dollars
GR7WT(20)	group 7 weight, tons
H	draft, feet
HEAD(20)	descriptive heading (alphanumeric)
HLA(20)	electronics hull area, sq ft
HLAR(20)	armament hull area, sq ft
HPMS	maximum sustained shaft horsepower
INDEX	control variable
JOPT	input option variable for machinery
KGTRY	initial KG estimate, feet
LEN	length between perpendiculars, feet
LRD	raised deck length, feet
MCST	miscellaneous costs, dollars

Nomenclature List (cont)

MTYPE	machinery type option
NCPO	number of chief petty officers (real)
NENL	number of enlisted men (real)
NOARM	number of armament input cards
NOELT	number of electronics input cards
NOFF	number of officers (real)
NOCPO	number of chief petty officers (integer)
NOCREW	number of enlisted men (integer)
NOOFF	number of officers (integer)
PALOAD	propulsion auxiliary electrical load, KW
PCE	propulsive coefficient at endurance speed
PCM	propulsive coefficient at maximum speed
RGEND	endurance range, nautical miles
SFCHHP	specific fuel consumption at half horsepower, lbs/SHP-hr
SFCMHP	specific fuel consumption at maximum horsepower, lbs/SHP-hr
SHPE	shaft horsepower at endurance speed
SHPM	shaft horsepower at maximum speed
TITLE(5,40)	line titles.(alphanumeric)
TOTCST	total lead ship cost, dollars
VEND	endurance speed, knots
VSUS	maximum sustained speed, knots
WACFUL	weight of aircraft fuel, tons
WCARGO	total cargo weight, tons
WFULLD	full load weight, tons

Nomenclature List (cont)

WLSHIP	light ship weight, tons
WTAC	total aircraft weight, tons
WTAMMO	total ammunition weight, tons
WTCREW	total crew weight, tons
WTFUEL	total ships fuel weight, tons
WTG1	total group 1 weight, tons
WTG2	total group 2 weight, tons
WTG3	total group 3 weight, tons
WTG4	total group 4 weight, tons
WTG5	total group 5 weight, tons
WTG6	total group 6 weight, tons
WTG7	total group 7 weight, tons
WTLO	weight of lub oil, tons
WTPE	weight of personal effects, tons
WTPS	weight of personnel stores, tons
XLM	machinery box length, feet

3.3 Subroutine XECUTE

3.3.1 Introduction

Subroutine XECUTE controls the execution of each trial case. All of the remaining subroutines except two are called by this routine. Error messages are also printed by this routine whenever a constraint of the program is violated.

In three cases, iteration control statements have been included in XECUTE. The first set of these statements controls the convergence of the speed-power estimate when maximum sustained horsepower is specified. A modified Newton-Raphson technique[2] is used with the slope approximated by a secant to the speed-power curve.

The second set of iteration control statements controls the convergence between estimated displacement and full load weight. A similar modified Newton-Raphson technique is used.

The last set deals with the convergence of the vertical center of gravity estimate. For this set there is a tendency for the values to oscillate and a Newton-Raphson technique could not be used. The average of the estimated and calculated values of KG is used instead. While this eliminates the oscillations, convergence may be slow in some cases.

A flow chart for this subroutine is shown in Figures 5a, 5b, 5c, and 5d.

XECUTE SUBROUTINE
FLOW CHART

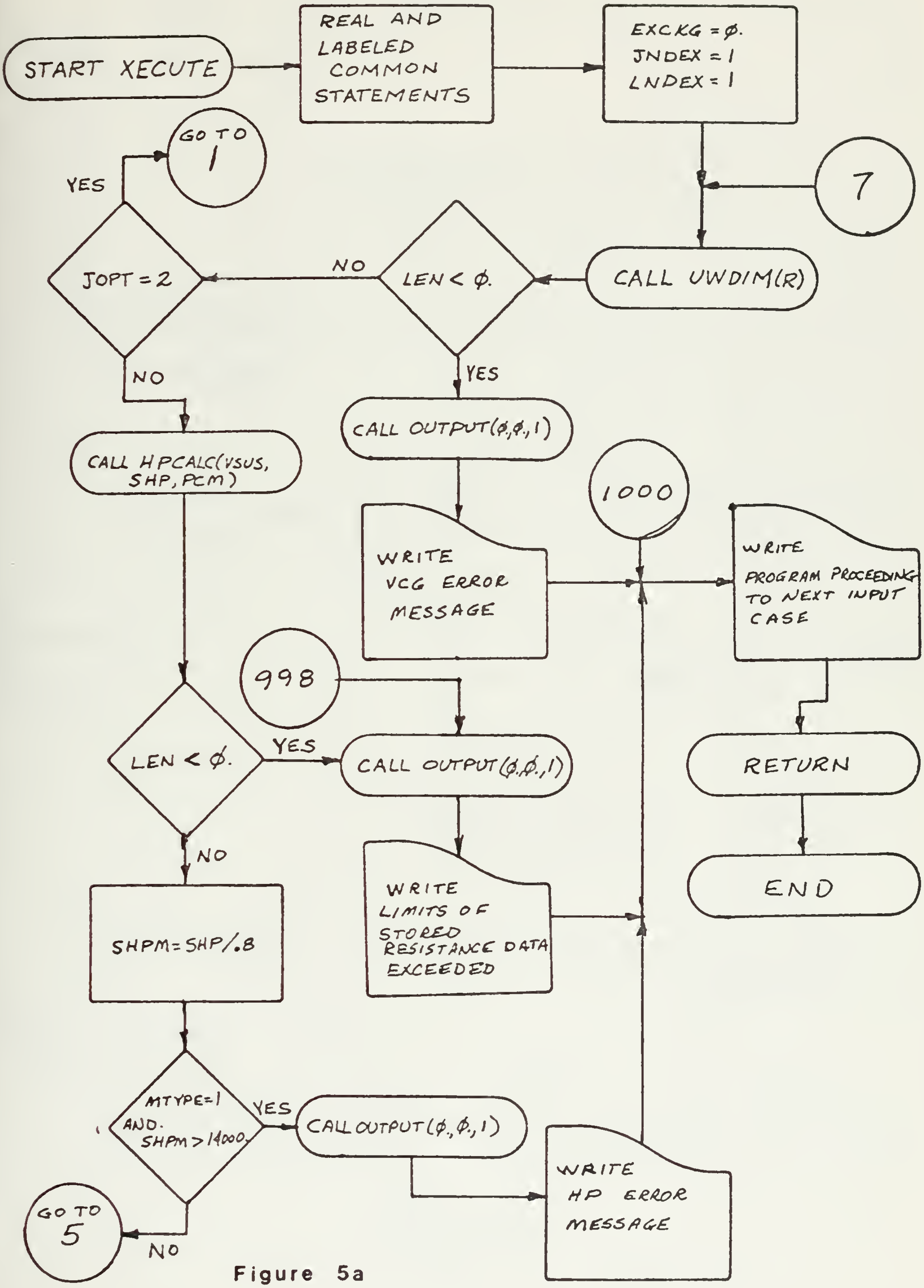


Figure 5a

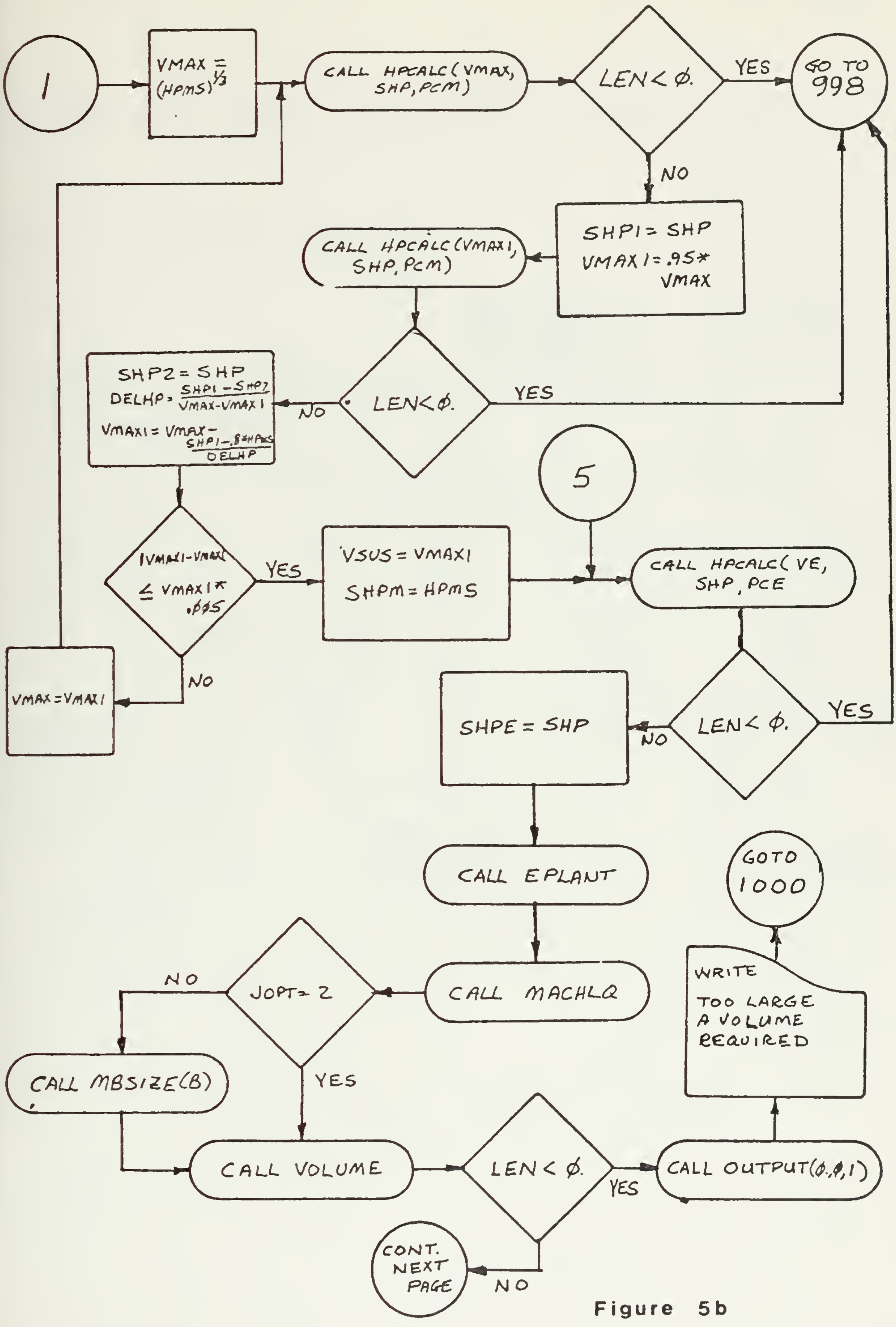

1
VMAX = (HPMS)^1/3
CALL HPCALC(VMAX, SHP, PCM)
LEN < Ø.
YES
GO TO 998
NO
SHP1 = SHP
VMAX1 = .95* VMAX
CALL HPCALC(VMAX1, SHP, PCM)
LEN < Ø.
YES
NO
SHP2 = SHP
DELHP = SHP1 - SHP2 / VMAX - VMAX1
VMAX1 = VMAX - SHP1 - .8*HPMS / DELHP
5
|VMAX1 - VMAX| ≤ VMAX1 * .ØØ5
YES
VSUS = VMAX1
SHPM = HPMS
CALL HPCALC(VE, SHP, PCE
NO
VMAX = VMAX1
LEN < Ø.
YES
SHPE = SHP
NO
CALL EPLANT
GOTO 1000
CALL MACHLQ
JOPT = 2
NO
WRITE TOO LARGE A VOLUME REQUIRED
CALL MBSIZE(B)
YES
CALL VOLUME
LEN < Ø.
CALL OUTPUT(Ø.,Ø,1)
YES
CONT. NEXT PAGE
NO

Figure 5b

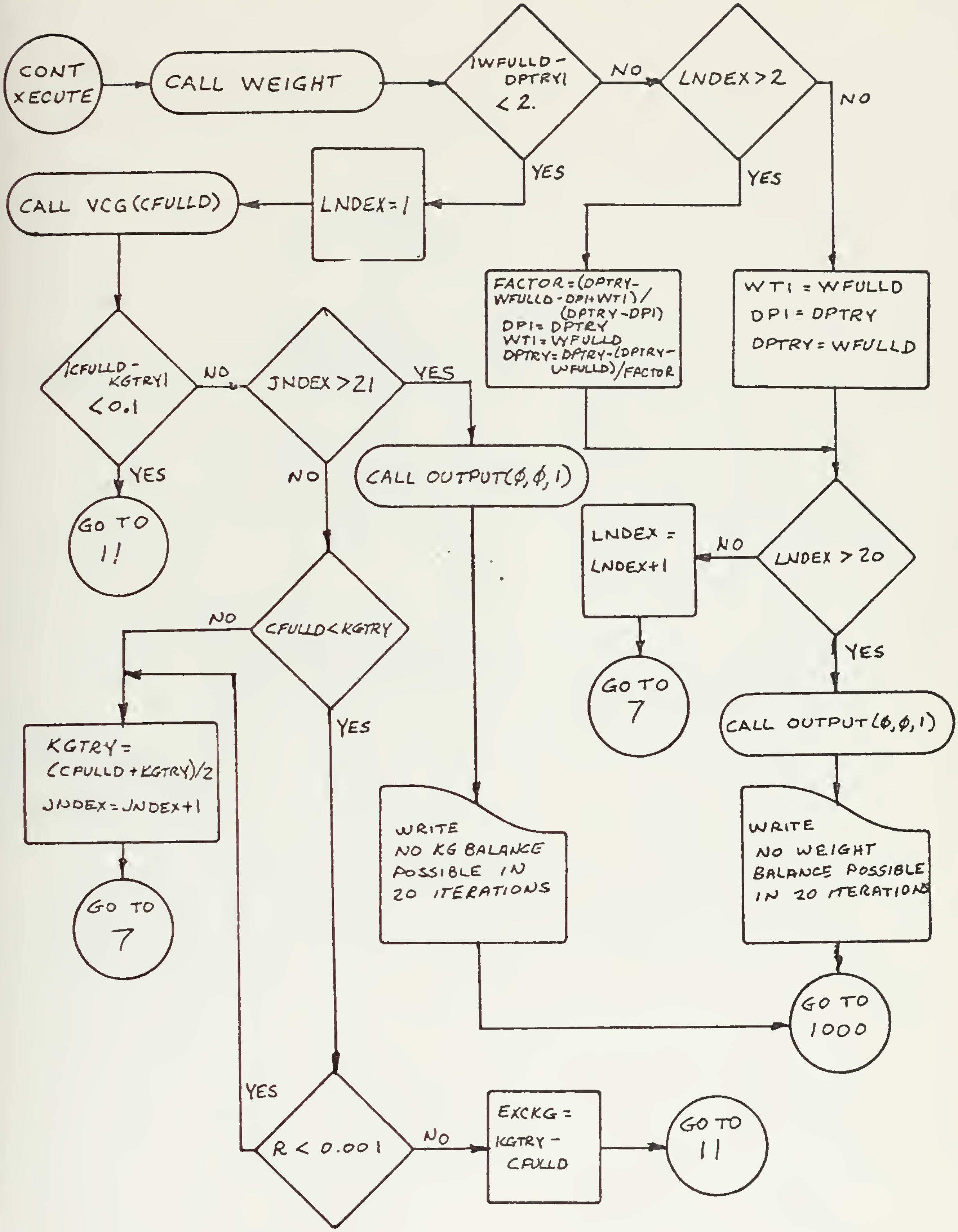

CONT XECUTE
CALL WEIGHT
|WFULLD - DPTRY| < 2.
NO
LNDEX > 2
NO
YES
YES
LNDEX = 1
CALL VCG(CFULLD)
FACTOR = (DPTRY - WFULLD - DP1 + WT1)/(DPTRY - DP1)
DP1 = DPTRY
WT1 = WFULLD
DPTRY = DPTRY - (DPTRY - WFULLD)/FACTOR
WT1 = WFULLD
DP1 = DPTRY
DPTRY = WFULLD
|CFULLD - KGTRY| < 0.1
NO
JNDEX > 21
YES
YES
NO
CALL OUTPUT(Ø,Ø,1)
GO TO 11
LNDEX = LNDEX + 1
NO
LNDEX > 20
YES
GO TO 7
CALL OUTPUT(Ø,Ø,1)
NO
CFULLD < KGTRY
YES
KGTRY = (CFULLD + KGTRY)/2
JNDEX = JNDEX + 1
GO TO 7
WRITE NO KG BALANCE POSSIBLE IN 20 ITERATIONS
WRITE NO WEIGHT BALANCE POSSIBLE IN 20 ITERATIONS
GO TO 1000
YES
R < 0.001
NO
EXCKG = KGTRY - CFULLD
GO TO 11

Figure 5c

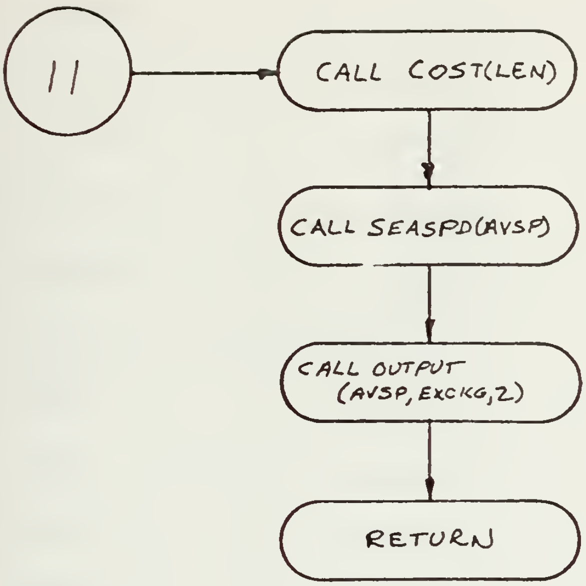

11
CALL COST(LEN)
CALL SEASPD(AVSP)
CALL OUTPUT (AVSP, EXCKG,2)
RETURN

Figure 5d

3.3.2 Input List for Subroutine XECUTE

DPTRY............LC(GG)

HPMS..............SCDA   Only if JOPT = 2

JOPT.............LC(CC)

KGTRY............LC(GG)

LEN..............LC(BB)

MTYPE............LC(CC)

PCE..............LC(CC)

PCM..............LC(CC)

VE...............LC(CC)

VSUS.............LC(CC)   Only if JOPT = 1

WFULLD...........LC(WW)

3.3.3 Statement Descriptions

REAL and COMMON statements will not be listed with individual subroutines but may be found in Appendix C.

```
EXCKG=0.
JNDEX=1
LNDEX=1
```

These statements initialize values for the excess KG variable, the VCG loop counter and the weight loop counter respectively.

```
  7 CALL UWDIM(R)
```

This subroutine is called to calculate the beam and draft of the ship. The variable R transfers the value of any excess KG.

```
IF(LEN.LT.0.) GOTO 999
```

If a beam to draft ratio of greater than 4.0 is

required to satisfy the stability requirements, LEN is set equal to -1000. in UWDIM. This signals XECUTE to print an error message and return control to MAIN.

```
IF(JOPT.EQ.2) GOTO 1
```

The next group of statements control the speed-power estimate. Two procedures are used depending on which performance input option is specified.

```
CALL HPCALC(VSUS,SHP,PCM)
IF(LEN.LT.0.) GOTO 998
GOTO 2
```

These statements are used if the sustained speed is specified. Subroutine HPCALC is designed to return a value of shaft horsepower, SHP, if speed and propulsive coefficient are specified. In this case VSUS is the speed and PCM the propulsive coefficient used.

LEN is used here also as a signal that an error message is required. A negative length, LEN, will occur if the limits of the C_r array are exceeded. The ranges of the C_r array are:

$$.48 \leq C_p \leq .70$$

$$2. \leq B/T \leq 4.$$

$$\text{for } .001 \leq C_v \leq .003$$

$$.5 \leq V/\sqrt{L} \leq 2.$$

$$\text{for } .003 \leq C_v \leq .006$$

$$.5 \leq V/\sqrt{L} \leq 1.3$$

The GOTO 2 statement causes the routine to skip the speed estimate used when JOPT = 2.

```
1 VMAX = (HPMS*200./LEN)**.33333
```

If the maximum sustained horsepower, HPMS, was specified, the following statements are used for estimating the maximum sustained speed. The statement given above provides a rough first guess at the speed.

```
4 CALL HPCALC(VMAX,SHP,PCM)
  IF(LEN.LT.0.) GOTO 998
  SHP1=SHP
  VMAX1=.95*VMAX
  CALL HPCALC(VMAX1,SHP,PCM)
  IF(LEN.LT.0) GOTO 998
  SHP2=SHP
```

Two points on the speed-power curve are calculated in the above statements, one point at VMAX and one point at .95 x VMAX. The constant, .95, was chosen arbitrarily to give a secant to the curve which has a slope close to the actual slope at VMAX. The same limits of the C_r array apply here.

```
DELHP=(SHP1-SHP2)/(VMAX-VMAX1)
```

This is the approximate value of

$$\frac{d(SHP)}{dV} \text{ at VMAX}$$

```
VMAX1=VMAX-(SHP1-.8*HPMS)/DELHP
```

By definition the maximum sustained speed is the speed that can be made when the shaft horsepower is 80 percent of the maximum sustained horsepower. This assumes the ship has a clean bottom and is operating in calm water. Therefore, the function to be solved is:

$$f(V) = SHP(V) - .8 \times HPMS = 0$$

The Newton-Raphson method is an iterative procedure

in which:

$$V_{k+1} = V_k - \frac{f(V_k)}{f'(V_k)}$$

$$\text{where } f'(V_k) = \left.\frac{d\ f(V)}{d\ V}\right|_{V_k}$$

In the present case:

V_k = VMAX

V_{k+1} = VMAX1

$f(V_k)$ = SHP1 - .8 x HPMS

$f'(V_k)$ = DELHP

DELHP is only an approximation to $f'(V_k)$; however, it produces very good convergence.

```
IF(ABS(VMAX1-VMAX).LE.VMAX1*.005) GOTO 3
```

The iteration stops when the difference between any two successive speed estimates is less than half a percent of the best estimate. The above iteration technique is very fast and convergence to these limits usually occurs in 3 to 4 iterations.

```
VMAX = VMAX1
GOTO 4
```

These statements are used if the two speed estimates are not within the above limit. The new velocity estimate is used and another iteration is run.

```
3 VSUS = VMAX1
  SHPM = HPMS
  GOTO 5
```

The above pair of values are saved for output and for use in other subroutines.

```
2 SHPM = SHP/.8
```

In the case where VSUS is specified, the value SHP

is equal to SHPM times .8 as before.

```
IF(MTYPE.EQ.1.AND.SHPM.GT.14000.) GOTO 997
```

If a diesel plant is specified, horsepowers of greater than 14000 are outside the range of validity of the model. An error message is printed if this occurs.

```
5 CALL HPCALC(VE,SHP,PCE)
  IF(LEN.LT.0.) GOTO 998
  SHPE=SHP
```

The endurance horsepower is calculated without regard to fouling or sea conditions. This statement is executed for both performance options.

```
CALL EPLANT
```

This subroutine is called to calculate the average electrical load at sea and to size the ships generators.

```
CALL MACHLQ
```

This subroutine is called to calculate the weight of fuel, lub oil and potable water required.

```
IF(JOPT.EQ.2) GOTO 6
CALL MBSIZE(B)
```

Subroutine MBSIZE calculates the length and minimum depth of the machinery box. If JOPT = 2 these values are given as input.

```
6 CALL VOLUME
  IF(LEN.LT.0) GOTO 996
```

Subroutine VOLUME sets the sheer line and balances the required area and available area. If insufficient area is available, the value of LEN will be negative.

```
CALL WEIGHT
```

All the weights not previously estimated or inputed

are calculated in this routine. The primary value returned is WFULLD, the full load weight.

```
IF(ABS(WFULLD-DPTRY).LT.2.) GOTO 8
```

The calculated full load weight is compared to the displacement estimate made earlier. If the two do not agree within 2 tons, a new estimate of displacement is made and the program returns to call UWDIM. If there is agreement, the program proceeds to calculate vertical center of gravity.

```
IF(LNDEX.GE.2) GOTO 9
WT1=WFULLD
DP1=DPTRY
DPTRY=WFULLD
GOTO 10
```

Two values of weight and two values of displacement are needed for the Newton-Raphson procedure explained below to work. On the first iteration, the above simplified procedure is used.

```
9 FACTOR=(DPTRY-WFULLD-DP1+WT1)/(DPTRY-DP1)
  DP1=DPTRY
  WT1=WFULLD
  DPTRY=DPTRY-(DPTRY-WFULLD)/FACTOR
```

In this case:

$$f(DPTRY) = DPTRY - WFULLD(DPTRY) = 0$$

Again a secant approximation is made to f'(DPTRY). This is the variable FACTOR.

$$DPTRY_{k+1} = DPTRY_k - \frac{f(DPTRY)}{f'(DPTRY)}$$

```
10 IF(LNDEX.GT.20) GOTO 995
```

In case the iteration does not converge, this statement

provides a safety valve to stop the loop. An error message is printed.

```
      LNDEX=LNDEX+1
      GOTO 7
```

A new iteration is run beginning with a call to UWDIM.

```
    8 CONTINUE
      LNDEX=1
      CALL VCG(CFULLD)
```

Once the full load weight is sufficiently close to displacement, the program proceeds to calculate KG. The weight counter is reset. The value CFULLD is the calculated KG. This value is compared with the previous estimate, KGTRY.

```
      IF(ABS(CFULLD-KGTRY).LT..1) GOTO 11
```

This iteration stops when the two KG values are less than 0.1 feet apart.

```
      IF(JNDEX.GT.21) GOTO 994
```

Again a safety valve is provided in case the iteration does not converge.

```
      IF(CFULLD.LT.KGTRY) GOTO 12
   13 KGTRY=(CFULLD+KGTRY)/2.
      JNDEX=JNDEX+1
      GOTO 7
   12 IF(R.LT..001) GOTO 13
      EXCKG=KGTRY-CFULLD
```

In some cases the minimum beam to draft ratio may provide more stability than is required to satisfy the GM criterion. The ship is still feasible if this occurs, but may be over designed. When this occurs R will have a value greater than 0. In fact, it will be equal to the excess KG when KGTRY is used in UWDIM. The input value

of KGTRY is modified in UWDIM by adding R. Therefore, the value of KGTRY at this point in the program is the maximum value of vertical center of gravity for which a minimum beam to draft ratio will still be valid. If CFULLD is less than this value there is no point in doing another iteration. Instead, the program continues and eventually prints the excess KG available as an output.

In all other cases a new estimate of KGTRY must be made. As mentioned earlier, this estimate is taken as the average of the initial estimate and final calculated value. This is done to prevent the two values from oscillating. As an example, in the case of the 378' WHEC, a KGTRY of 14 feet returned a CFULLD of 16 feet. A KGTRY of 16 feet returned a CFULLD of 14 feet. This oscillation may not occur in other cases, but the averaging estimate used will converge in every case, although possibly at a slow rate.

```
 11 CONTINUE
    CALL COST(LEN)
```

Subroutine COST calculates any remaining cost items not given as input.

```
    CALL SEASPD(AVSP)
```

This subroutine estimates an average speed, AVSP, in the North Atlantic Ocean which includes the effects of sea state.

```
    CALL OUTPUT(AVSP,EXCKG,2)
```

Subroutine OUTPUT contains the write statements for printing all the output and input data. The value 2 causes OUTPUT to

print both the input and output data.

```
      RETURN
```

The present input case has been completed and control is returned to the MAIN program for more data.

The error message statements are all similar in format and generally self explanatory. Only one typical one will be discussed.

```
  994 CALL OUTPUT(0.,0.,1)
```

Subroutine OUTPUT is called with a value of 1. This directs OUTPUT to print only the input data.

```
      WRITE(5,106)
  106 FORMAT(///' NO BALANCE BETWEEN ASSUMED AND CALC KG
     1     WITHIN 0.1 FEET COULD BE MADE IN 20 ITERATIONS'///)
      GOTO 1000
 1000 WRITE(5,102)
  102 FORMAT('PROGRAM PROCEEDING TO NEXT INPUT CASE'///)
      RETURN
      END
```

The program prints the appropriate error message and returns for more data. This concludes subroutine XECUTE.

3.3.4 Output List for Subroutine XECUTE

DPTRY..........LC(GG)

EXCKG............SCDA

KGTRY..........LC(GG)

SHPE...........LC(CC)

SHPM...........LC(CC)

3.3.5 Nomenclature List

All variables have the same definition as given in the MAIN program nomenclature list except for the following:

AVSP	average speed in N.A. Ocean, knots
CFULLD	vertical center of gravity, KG, feet
DELHP	derivative of horsepower function
DP1	used to store DPTRY value, tons
EXCKG	excess KG, feet
FACTOR	derivative of weight function
JNDEX	vcg counter
LNDEX	weight counter
R	excess KG, feet
RE	same as RGEND in MAIN
SFCH	same as SFCHHP in MAIN
SFCM	same as SFCMHP in MAIN
SHP	dummy used for shaft horsepower
SHP1	dummy used for shaft horsepower
SHP2	dummy used for shaft horsepower
VE	same as VEND in MAIN
VMAX	dummy used for speed, knots
VMAX1	dummy used for speed, knots
WT1	used to store WFULLD, tons

3.4 Subroutine UWDIM

3.4.1 Introduction

Three of the important variables determining the underwater hull dimensions are given as input. These are length, C_p and C_x. Two others, the beam and draft, are calculated in UWDIM. The waterplane coefficient, C_{wp}, is also calculated, but only as a linear function of C_p.

Displacement is an input to this subroutine and therefore the value of beam times draft is fixed since:

$B \times T = \text{Displacement} \times 35./(L_{bp} \times C_p \times C_x)$ Ref.(3)

Reference (3) may be referred to for a detailed definition of the naval architectural variables used in this routine.

The beam to draft ratio, B/T, is determined by the GM/B criterion. The GM available is given by the formula:

$GM = KB + BM - KG - \text{Free surface correction}$ Ref.(3)

Values for KG, free surface correction and GM/B are inputs to this routine. A value for KB is estimated using Morrish's approximate formula:[3]

$KB = T - 1/3 \times (T/2 + \nabla/A)$

where T is the draft in feet

∇ is the volume of displacement = $B \times T \times L_{bp} \times C_p \times C_x$, cu ft

A is the waterplane area = $B \times L_{bp} \times C_{wp}$, sq ft

Substituting for ∇ and A gives:

$KB = T \times (5/6 - (C_p \times C_x)/(3 \times C_{wp}))$

A value for BM is estimated using:

$$BM = \frac{Lbp \times B^3 \times C_\alpha}{\nabla}$$

where C_α is a transverse moment of inertia coefficient which is assumed to be a linear function of C_{wp}.

A number of coefficients are used in this routine which are defined by the above equations. These are listed below.

C1 = DPTRY*35./(LEN*CP*CX) = B x T

C2 = .833 - CP*CX/(3*CWP) = KB/T

C3 = LEN*CALPH/(DPTRY*35.) = BM/B^3

C4 = KG + FRSC

C5 = GM/B = GMMUL

Figure 7 gives a typical plot of the equation:

$$KB + BM - GM = C2 \times T + \frac{C3 \times C1^3}{T^3} - \frac{C1 \times C5}{T}$$

The curve shown was calculated using data for a 378' WHEC.

The value of KG is also plotted in Figure 7. In the discussion below, KG refers to the value of KG + FRSC. A variable R is now introduced with a value of:

R = KB + BM - GM - KG_{TRY}

When R = 0, the stability criterion that GM = C5 x B is just satisfied. This is the desired solution. This point is shown as point 3 in Figure 7.

However, the solution is only valid provided point 3 lies within satisfactory limits of beam to draft ratio. These limits are specified by the speed-power estimation

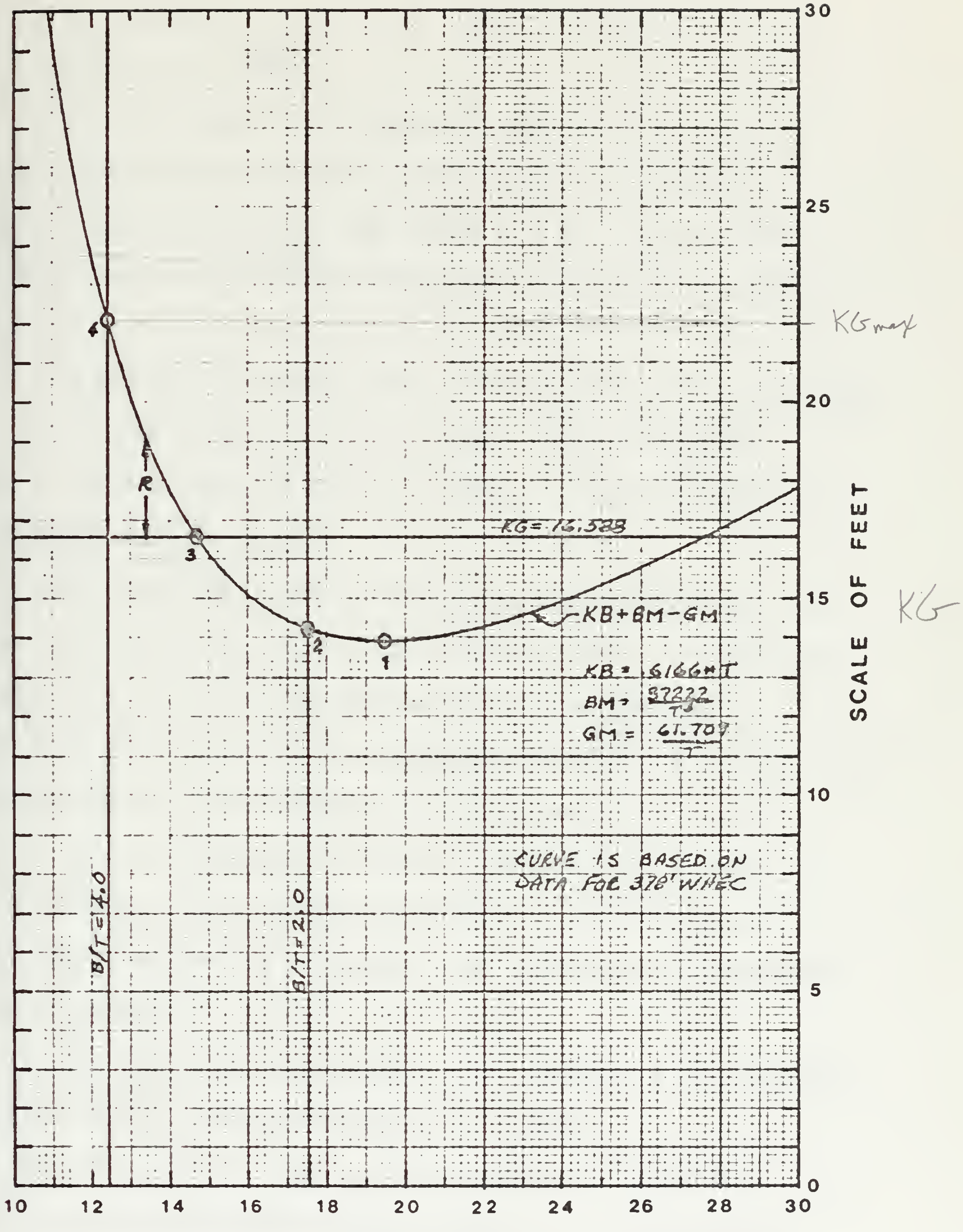

30
25
20
15
10
5
0
10 12 14 16 18 20 22 24 26 28 30
SCALE OF FEET
DRAFT-FT
KG max
KG
R
KG = 16.588
KB+BM-GM
KB = .6166 * T
BM = 37222 / T
GM = 61.709 / T
CURVE IS BASED ON
DATA FOR 378' WHEC
B/T = 4.0
B/T = 2.0
1
2
3
4

Figure 7

to be:

$$2. \leq B/T \leq 4.$$

or since $B = C1/T$

$$\sqrt{C1/4} \leq T \leq \sqrt{C1/2}$$

It can be seen from Figure 7 that if the value of KG is lower than the value of KB + BM - GM at point 1 there would be no draft for which R = 0. The minimum GM that could be provided would still be greater than C5 x B.

The solution method used in UWDIM proceeds as follows:

(1) The value of B/T at point 1 is calculated. Then a check is made to see if point 1 lies between the acceptable limits of B/T.

(2) If point 1 lies within the limits of B/T, the value of R is calculated. If R is positive, no solution exists to R = 0 but the ship may still be feasible. In this case the minimum GM is greater than C5 x B. When this occurs the KG estimate is raised until R = 0 at point 1 and the program returns to subroutine XECUTE. If it is found later that the actual KG of the ship is lower than the new KG estimate, the difference is printed as an excess KG.

$\frac{GM}{B} > 0.1$

If the value of R at point 1 is negative, the program executes the procedure described in step 4.

(3) If point 1 does not lie within acceptable limits of B/T, the value of R at point 2 is calculated. If R is positive at this point the procedure is the same

as that outlined in step 2. If R is negative, execution proceeds to step 4.

(4) If the value of KG is greater than the value of KB + BM - GM at point 1 or point 2, the value of R at point 4 is calculated. If the value of R is negative at this point, no draft can be specified within the limits of B/T that will satisfy the stability criterion and the program will have to go on to another input case.

If R is positive at point 4, the solution must lie between point 4 and point 1 or point 2, whichever is lower. It is assumed that if point 1 is within the limits on B/T that the solution does not lie between point 1 and point 2.

(5) To solve for the draft at which R = 0, a synthetic division technique is used together with the Newton-Raphson iteration technique. This is sometimes known as the Birge-Vieta method.[2] The equation for R must be modified slightly to use this technique.

$$f(T) = T^3R/C_2 = T^4 - C_4T^3/C_2 - C_1C_5T^2/C_2 + C_3C_1{}^3/C_2 = 0$$

In the Birge-Vieta method three columns are used as shown below:

$$\begin{array}{lll} 1 & 1 & 1 \\ a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \\ a_4 & b_4 & \end{array}$$

The values in the first column are the coefficients in the equation for f(T), namely:

$$a_1 = -C_4/C_2,\ a_2 = -C_1C_5/C_2,\ a_3 = 0,\ a_4 = C_3C_1{}^3/C_2$$

The values in columns two and three are calculated using the equations:

$b_i = a_i + z \times b_{i-1}$

$c_i = b_i + z \times c_{i-1}$

where z is the current estimate of the draft, T.

The new estimate of draft is then:

$z_{new} = z - b_4/c_3$

New values are computed for columns two and three using z_{new}. The procedure starts with the draft at point 4 and continues until the difference between z_{new} and z is sufficiently small. This iteration procedure is very fast and usually only three or four iterations are required.

A flow chart for this subroutine is shown in Figures 6a and 6b.

3.4.2 Input List for Subroutine UWDIM

C4............LC(GG)

C5............LC(GG)

CP............LC(GG)

CX............LC(GG)

DISPL.........LC(GG)

FRSC..........LC(GG)

LEN...........LC(BB)

UWDIM SUBROUTINE
FLOW CHART

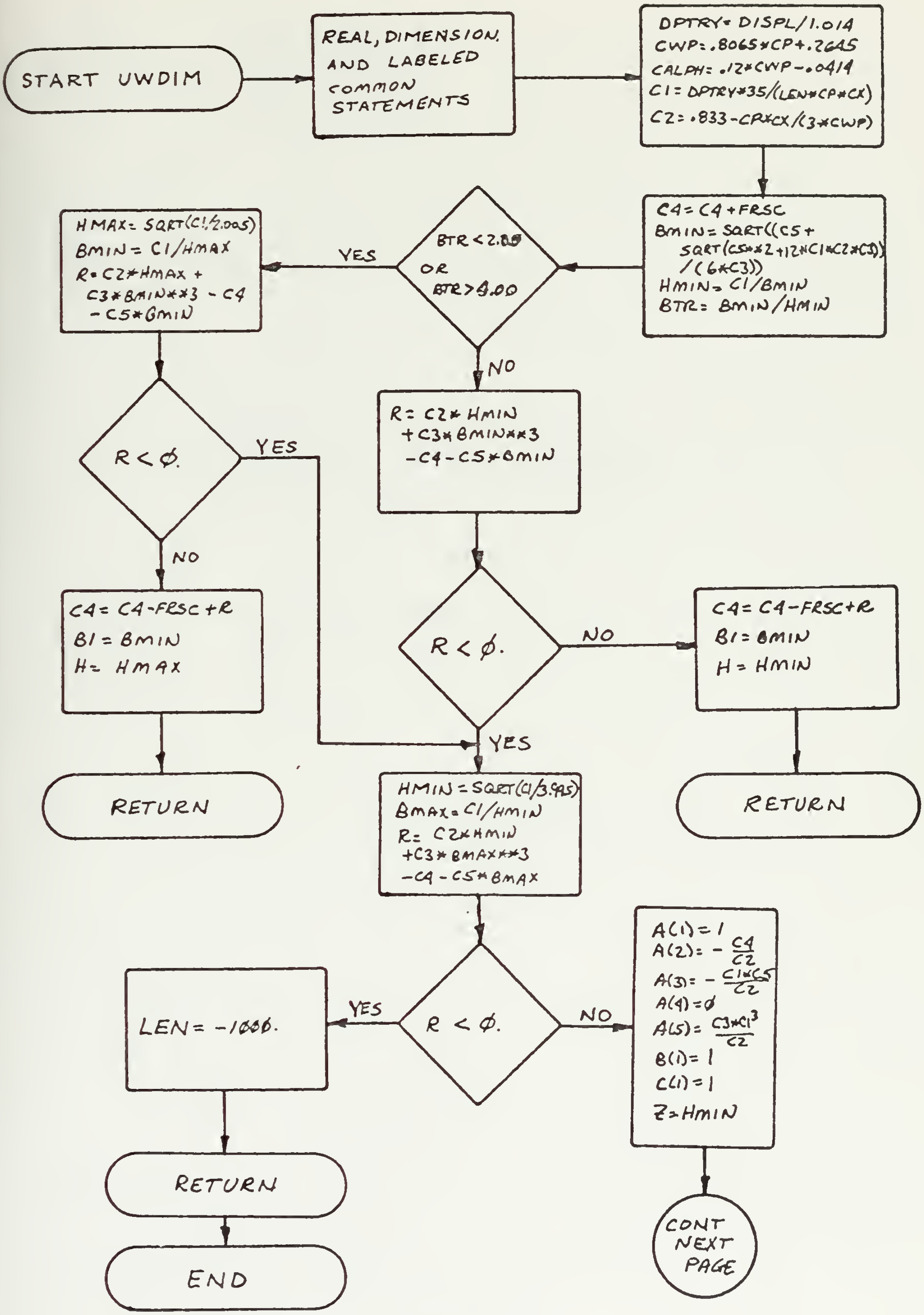


Figure 6a

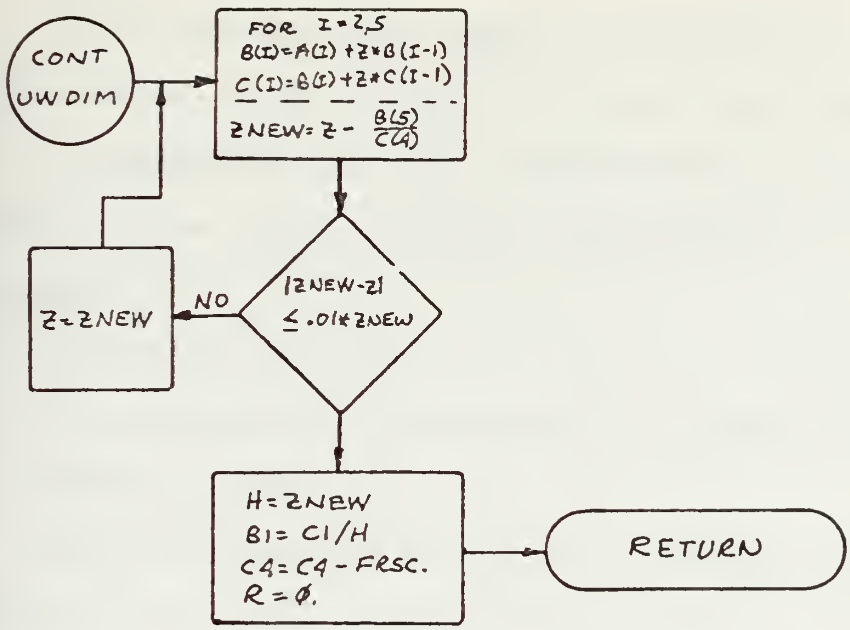

CONT
UWDIM
FOR I=2,5
B(I)=A(I)+Z*B(I-1)
C(I)=B(I)+Z*C(I-1)
ZNEW=Z - B(5)/C(4)
Z=ZNEW
NO
|ZNEW-Z|
≤ .01*ZNEW
H=ZNEW
B1= C1/H
C4=C4-FRSC.
R=Ø.
RETURN

Figure 6b

3.4.3 Statement Descriptions

```
DPTRY = DISPL/1.014
```

DISPL has the value assigned to DPTRY in other subroutines. It is assumed that the total displacement is 1.4 percent greater than the molded displacement. DPTRY has the value of molded displacement in this subroutine.

```
CWP=.8065*CP+.2645
```

This relationship is plotted in Figure 8.

```
CALPH=.12*CWP-.0414
```

This relationship is plotted as Figure 8-8(b) in Reference (1). This relationship applies to destroyer ship types but was not checked against Coast Guard designs.

```
C1=DPTRY*35./(LEN*CP*CX)
C2=.833-CP*CX/(3.*CWP)
C3=LEN*CALPH/(DPTRY*35.)
C4=C4+FRSC
```

The derivation of these coefficients is described in the introduction to this section.

```
BMIN=SQRT((C5+SQRT(C5**2+12.*C1*C2*C3))/(6.*C3))
HMIN=C1/BMIN
BTR=BMIN/HMIN
IF(BTR.LT.2..OR.BTR.GT.4.) GOTO !
```

The ratio of B/T at point 1 in figure 7 is calculated using these statements. The formula for BMIN is derived by setting dR/dB = 0 and solving for B.

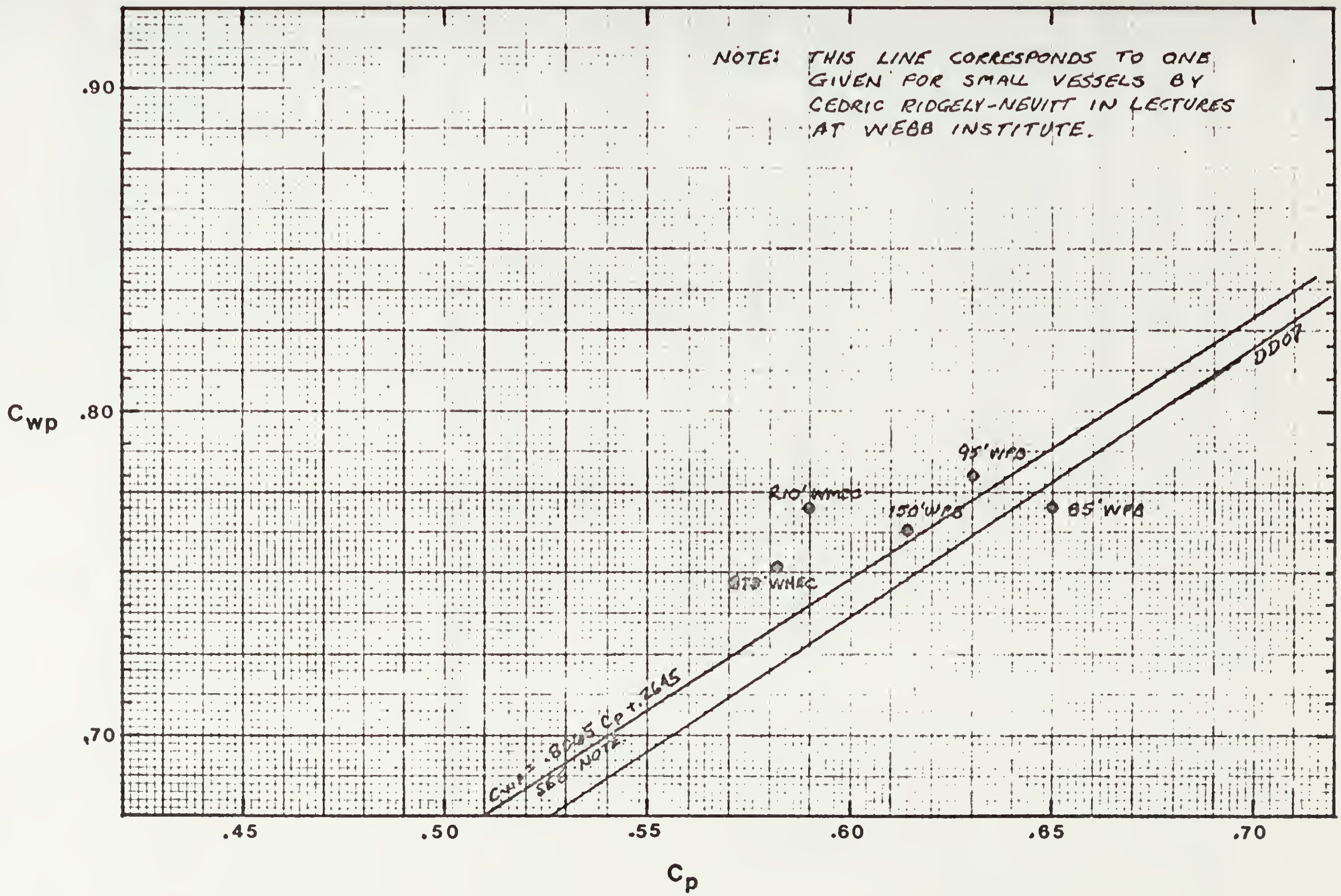

NOTE: THIS LINE CORRESPONDS TO ONE GIVEN FOR SMALL VESSELS BY CEDRIC RIDGELY-NEVITT IN LECTURES AT WEBB INSTITUTE.
.90
.80
.70
C_{wp}
.45
.50
.55
.60
.65
.70
C_p
C_{wp} = .8605 C_p +.2645
SEE NOTE
DDOP
95' WPB
R10' WMEB
150' WPB
85' WPB
313' WHEC

Figure 8

```
R=C2*HMIN+C3*BMIN**3-C4-C5*BMIN
IF(R.LE.0) GOTO 2
C4=C4-FRSC+R
B1=BMIN
H=HMIN
RETURN
```

These statements compute the value of R if point 1 lies within the acceptable B/T limits. If R is positive, the program returns the value of beam and draft at point 1 and increases the estimate of KG by R.

```
1 HMAX=SQRT(C1/2.005)
  BMIN=C1/HMAX
  R=C2*HMAX+C3*BMIN**3-C4-C5*BMIN
  IF(R.LE.0) GOTO 2
  C4=C4-FRSC+R
  B1=BMIN
  H=HMAX
  RETURN
```

These values are calculated for point 2 in Figure 7. Actually they are slightly off of point 2 to insure an acceptable value in the speed-power routine.

```
2 HMIN=SQRT(C1/3.995)
  BMAX=C1/HMIN
  R=C2*HMIN+C3*BMAX**3-C4-C5*BMAX
  IF(R.LT.0.) GOTO 6
```

These values are calculated for point 4 in Figure 7. If R is negative at this point, an error message must be printed.

```
  A(1)=1.
  A(2)=-C4/C2
  A(3)=-C1*C5/C2
  A(4)=0.
  A(5)=C3/C2*C1**3
  B(1)=1.
  C(1)=1.
  Z=HMIN
3 DO 4 I = 2,5
  B(I)=A(I)+Z*B(I-1)
4 C(I)=B(I)+Z*C(I-1)
```

The columns of the Birge-Vieta method are calculated in these equations.

```
      ZNEW=Z-B(5)/C(4)
      IF(ABS(ZNEW-Z).LE..01*ZNEW) GOTO 5
      Z=ZNEW
      GOTO 3
```

A revised estimate of draft is calculated and the iteration is repeated unless the difference between the old and new values is less than 1 percent of the new estimate.

```
    5 H=ZNEW
      B1=C1/H
      C4=C4-FRSC
      R=0.
      RETURN
```

The results are returned for point 3 in Figure 7.

```
    6 LEN = -1000.
      RETURN
      END
```

These statements signal subroutine XECUTE to print an error message and proceed with a new data case.

3.4.4 Output List for Subroutine UWDIM

B1..............LC(GG)

CWP.............LC(GG)

H...............LC(GG)

3.4.5 Nomenclature List

All variables have the same definition as given in the MAIN program nomenclature except for the following:

A(5)	column 1 of the Birge-Vieta method
B(5)	column 2 of the Birge-Vieta method

Nomenclature List (cont)

B1	Beam, same as B in MAIN
BMAX	dummy value of beam
BMIN	dummy value of beam
BTR	beam to draft ratio
C(5)	column 3 in of the Birge-Vieta method
C1	coefficient, see text
C2	coefficient, see text
C3	coefficient, see text
C4	KG or KG + FRSC, feet
C5	GMMUL in MAIN
CALPH	coefficient, see text
DISPL	DPTRY in MAIN
HMAX	dummy value of draft
HMIN	dummy value of draft
I	index variable
R	KB + BM - GM - KG - FRSC
Z	dummy value of draft
ZNEW	dummy value of draft

3.5 Subroutine HPCALC

3.5.1 Introduction

Subroutine HPCALC performs a Taylor's Standard Series power estimation.[7] The procedure used is very similar to the hand calculating procedure. However, two problems are of interest with regard to doing the calculations on a computer. First, the C_r curves plotted in Reference (7) must be converted to array form and stored in the program. Subroutine CRVAL, described in Section 3.6, chooses the correct value of C_r from this stored array. Second, the surface area of the hull must be estimated.

One approximate formula for wetted surface is:

$S = 1.7 \cdot L \cdot T + V/T$[3]

where L is the ship length

T is the draft

V is the volume of displacement

This form was used as a starting point and an empirical relationship was derived to bring the wetted surface more closely in line with that specified on the curves given in Reference (7). To do this a number of points were chosen on the curves given. These points were compared to the above formula and some correcting factors for B/T, C_v and C_p were added to reduce the difference. The formula given below gives values within 5 percent of the values calculated from the curves of Reference (7) over the entire range.

$$S = (1.7 \cdot L \cdot T + V/T)(.0053(B/T)^2 - .02(B/T) + 3 \cdot C_v + .08 \cdot C_p + .926)$$

This formula is probably not the best method for estimating the surface area. One method would be to convert the curves to arrays and interpolate to find the correct area. Such a method requires much more time and compute storage to produce a result only slightly better than this formula. Most of the error between a power calculated by this routine and by hand is probably due to error in the surface area prediction.

A flow chart for this routine is given in Figure 9.

3.5.2 Input List for HPCALC Subroutine

B..............LC(GG)

CP.............LC(GG)

DELCF..........LC(CC)

DPTRY..........LC(GG)

H..............LC(GG)

LEN............LC(BB)

PC...............SCDA

VK...............SCDA

3.5.3 Statement Descriptions

DISPL=DPTRY/1.014

DISPL is the molded displacement. It is assumed that the total displacement is 1.4 percent greater than the molded displacement.

```
VOL=DISPL*35.
BDR=B/H
RN=VK*LEN*132050.
CF=.075/(ALOG10(RN)-2.)**2+DELCF
SLRAT=VK/(SQRT(LEN))
CV=VOL/(LEN)**3
```

HPCALC SUBROUTINE FLOW CHART

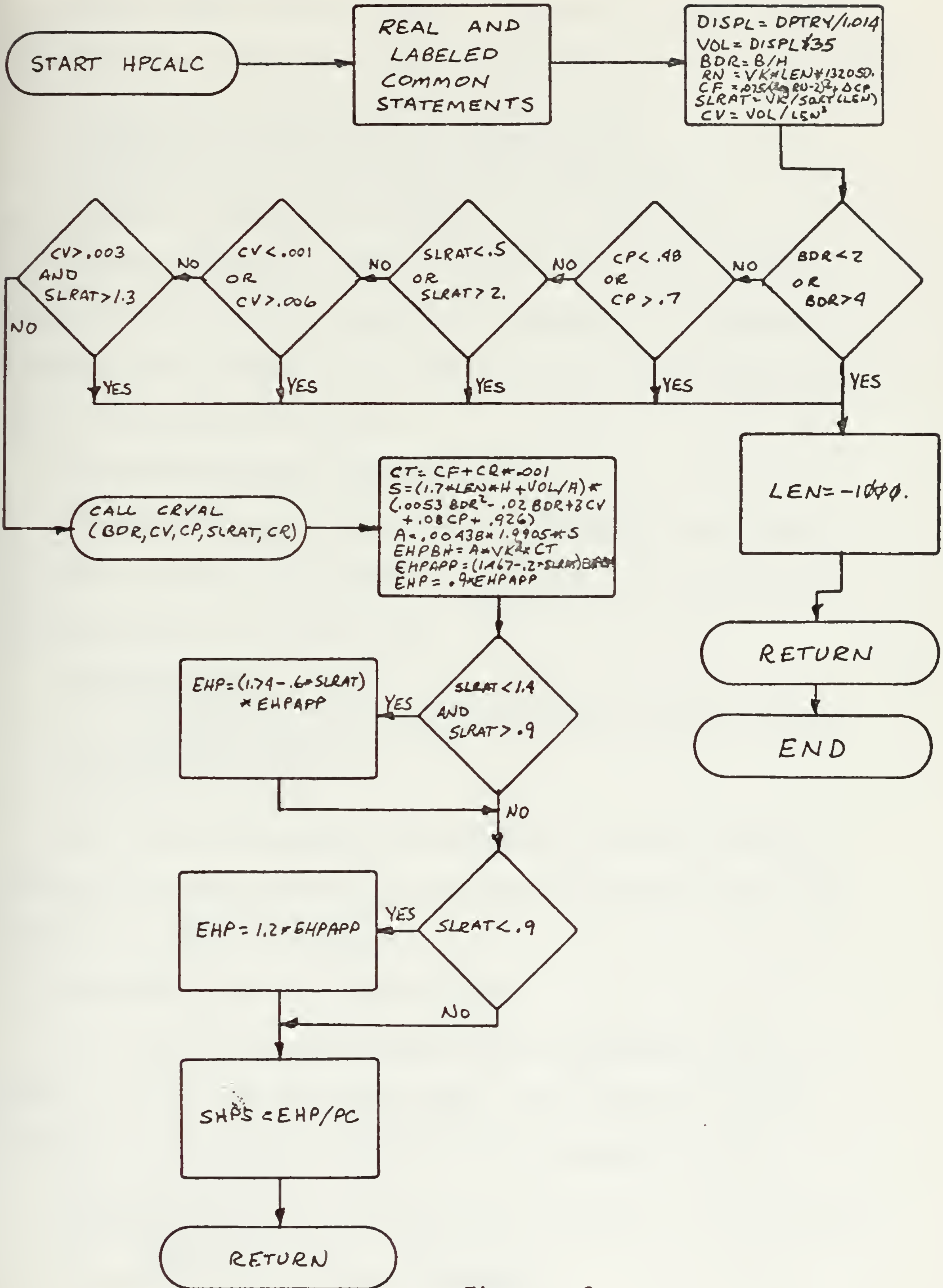


Figure 9

These formulas calculate, respectively, volume of displacement, beam to draft ratio, Reynold's number, C_f, speed length ratio, and C_v. C_f is the coefficient of frictional resistance calculated based on the ITTC line.

```
IF(BDR.LT.2..OR.BDR.GT.4.) GOTO 1000
IF(CP.LT..48.OR.CP.GT..7) GOTO 1000
IF(SLRAT.LT..5.OR.SLRAT.GT.2.) GOTO 1000
IF(CV.LT..001.OR.CV.GT..006) GOTO 1000
IF(CV.GT..003.AND.SLRAT.GT.1.3) GOTO 1000
```

These statements check to make sure none of the constraints of the C_r array are violated. If any is violated, the program will write an error message and go to the next input case.

```
CALL CRVAL(BDR,CV,CP,SLRAT,CR)
```

This subroutine is called to determine the value CR, the residuary resistance coefficient. The routine is described in section 3.6.

```
CT=CF+CR*.001
S=(1.7*LEN*H+VOL?H)*(.0053*BDR*BDR-.02*BDR+3.*CV+
    .08*CP+.926)
A=.00438*1.9905*S
EHPBH=A*VK**3*CT
```

The total resistance coefficient, wetted surface and finally the bare hull effective horsepower are calculated in these statements.

```
EHPAPP=(1.467-.2*SLRAT)*EHPBH
```

The effective horsepower with appendages has been based on data for the 378' WHEC. This data is shown in Figure 10 together with the above approximation.

```
EHP=.9*EHPAPP
IF(SLRAT.LT.1.4.AND.SLRAT.GT..9)EHP=(1.74-.6*SLRAT)*
    EHPAPP
IF(SLRAT.LE..9) EHP=1.2*EHPAPP
```

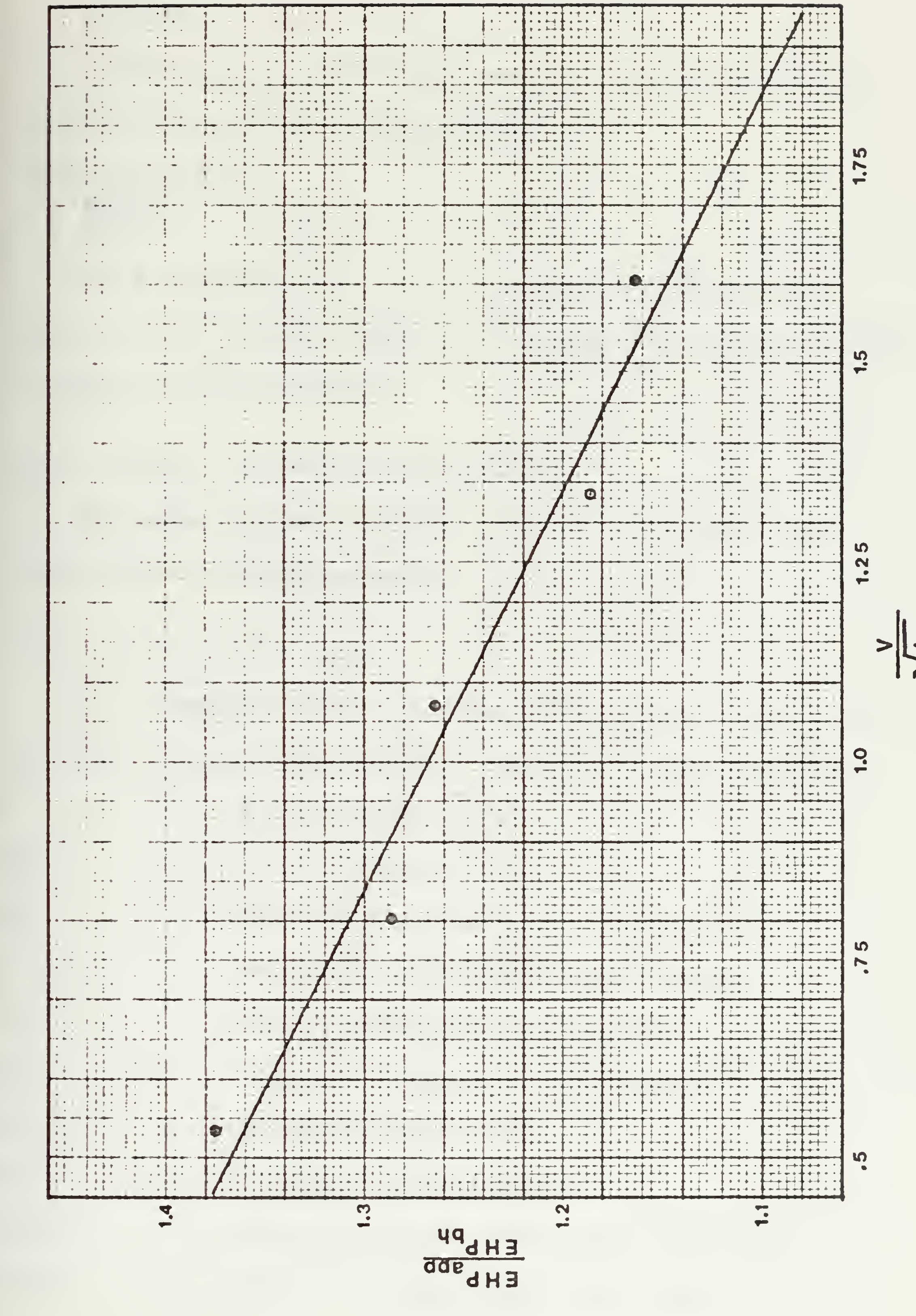


Figure 10

These equations approximate the EHP/EHP_{Taylor} curve for the 378' WHEC as shown in Figure 11.

```
     SHP=EHP/PC
     RETURN
```

Finally, the shaft horsepower is calculated using the input propulsive coefficient.

```
1000 LEN= -1000.
     RETURN
     END
```

If a constraint of the C_r array is violated the value of LEN is made negative to signal subroutine XECUTE to write an error message.

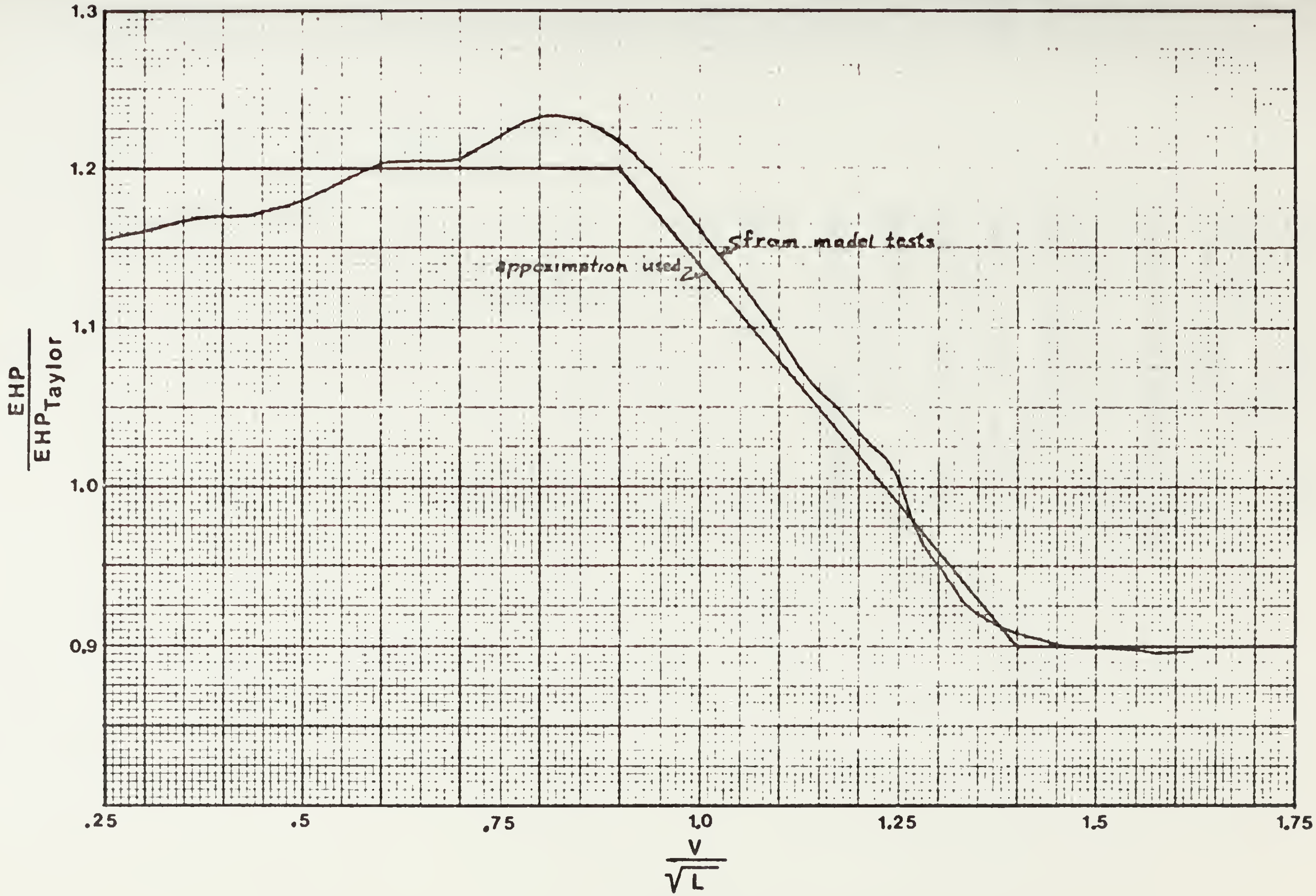
3.5.4 Output for Subroutine HPCALC

The only output is SHPS, which is returned as a call statement dummy argument.

3.5.5 Nomenclature List

All variables have the same definition as given in the MAIN program nomenclature except for the following:

A	dummy coefficient
BDR	beam to draft ratio
CF	frictional resistance coefficient
CR	residuary resistance coefficient
CT	total resistance coefficient
CV	Taylor's volumetric coefficient
DISPL	molded displacement
EHP	effective horsepower
EHPAPP	effective horsepower with appendages
EHPBH	effective horsepower bare hull



1.3
1.2
1.1
1.0
0.9
$\frac{EHP}{EHP_{Taylor}}$
from model tests
approximation used
.25
.5
.75
1.0
1.25
1.5
1.75
$\frac{V}{\sqrt{L}}$

Figure 11

Nomenclature List (cont)

PC	propulsive coefficient
RE	same as RGEND in MAIN
RN	Reynold's number
S	wetted surface, sq ft
SFCH	same as SFCHHP in MAIN
SFCM	same as SFCMHP in MAIN
SHPS	shaft horsepower
SLRAT	speed length ratio
VE	same as VEND in MAIN
VK	speed in knots
VOL	volume of displacement

3.6 Subroutine CRVAL

3.6.1 Introduction

Although this routine is physically one of the longest in the cutter model, the job it performs is one of the simplest. Its only function is to choose from stored data arrays the values of the residuary resistance coefficient, C_r, which straddle the input point and then to interpolate to find the value of C_r at the input point. The input point is specified by four variables. The value of each of these four-beam to draft ratio, C_p, C_v, and speed length ratio-is specified as input to the routine.

The constants stored in the three arrays which contain the C_r data were determined using the curves given in Reference (7). Although the three arrays - CR1, CR2, and CR3 - are each one dimensional, the data they contain is four dimensional, varying with each of the four variables which specify the input point. Each of the arrays contains values for beam to draft ratios of 2.25, 3.0, and 3.75. For each beam to draft ratio C_p was varied from 0.48 to 0.70 in steps of 0.02. For each of these values of B/T and C_p, all the possible combinations of C_v and speed length ratio given below were stored.

In array CR1 is stored data for C_v values of 0.001 and 0.002 and speed length ratios of 0.5 to 2.0 in steps of 0.1. Array CR2 corresponds to C_v values of 0.003,

0.004, and 0.005 plus speed length ratios from 0.5 to 1.3 in steps of 0.1. Data for a C_v value of 0.006 and speed length ratios of 0.5 to 1.0 in steps of 0.1 is stored in CR3.

In each of the three arrays, the first element corresponds to the lowest value of each of the four input variables. Speed lengcn ratio is increased most rapidly followed by C_p, C_v and finally beam to draft ratio.

The limits of the C_r arrays given above are extended somewhat by extrapolation. Beam to draft ratios between 2.0 and 4.0 are accepted. The limiting value on C_v has been extended by 0.001 for speed length ratios between 1.0 and 2.0. The maximum ranges that are accepted are given below.

$$2.0 \leq B/T \leq 4.0$$

$$.48 \leq C_p \leq .70$$

$$.001 \leq C_v \leq .006 \quad \text{for } 0.5 \leq V/\sqrt{L} \leq 1.3$$

$$.001 \leq C_v \leq .003 \quad \text{for } 0.5 \leq V/\sqrt{L} \leq 2.0$$

Sixteen values of C_r are required to straddle the input values of B/T, C_p, C_v, and $V/\sqrt{L}$. After these sixteen numbers have been chosen, the value of C_r at the input point is found by interpolation. A total of fifteen interpolations are required, eight to select the correct speed length ratio, four to select the correct C_p, two to select the correct beam to draft ratio, and a final one to select the correct C_v.

Even with the extensions listed earlier, the constraints

on the combined C_r array cause the major limitations of the cutter model. The C_r array data is listed in Appendix D. A flow chart for this routine is shown in Figures 12a and 12b.

3.6.2 Input List for Subroutine CRVAL

BTR...............SCDA

CP................SCDA

CR1(1152).......LC(TT)

CR2(972)........LC(TT)

CR3(216)........LC(TT)

CV................SCDA

VL................SCDA

3.6.3 Statement Descriptions

```
I1(J,K,L,M)=(K-1)*384+(J-1)*192+(L-1)*16+M
I2(J,K,L,M)=(K-1)*324+(J-3)*108+(L-1)*9+M
I3(J,K,L,M)=(K-1)*72+(L-1)*6+M
```

These are statement functions which convert the four dimensions - J, K, L, and M - into a single dimension for use with arrays CR1, CR2, and CR3 respectively.

```
IF(BTR.GE.3.) K1=2
IF(BTR.LT.3.) K1=1
K2=K1+1
```

An index is chosen in these statements for the beam to draft ratio below the input point and above the input point.

```
  CP1=.68
3 IF(CP-CP1+.0001) 1,2,2
1 CP1=CP1-.02
  GOTO 3
2 L1=IFIX((CP1-.46)*50.1)
  L2=L1+1
```

CRVAL SUBROUTINE
FLOW CHART

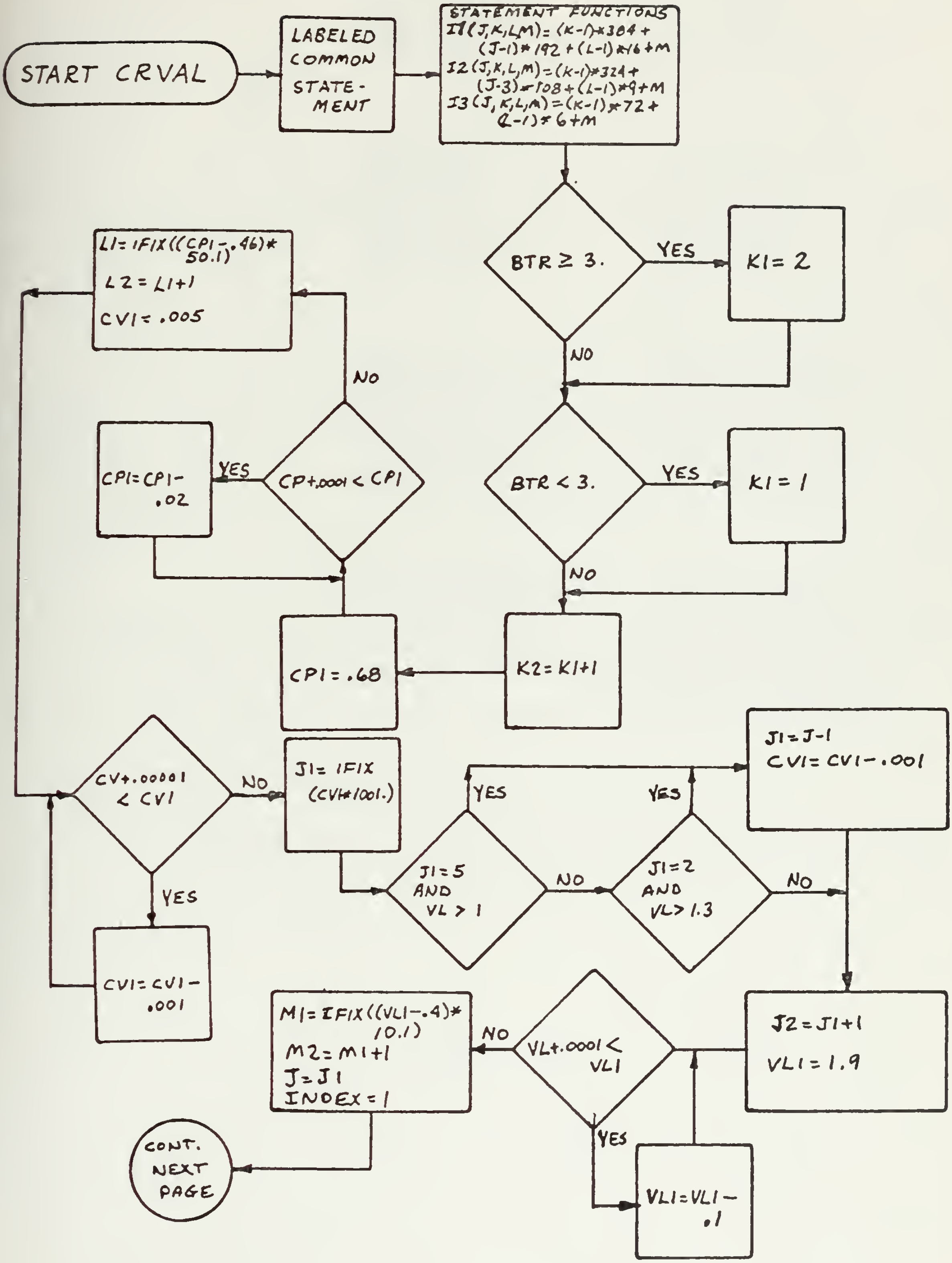


Figure 12a

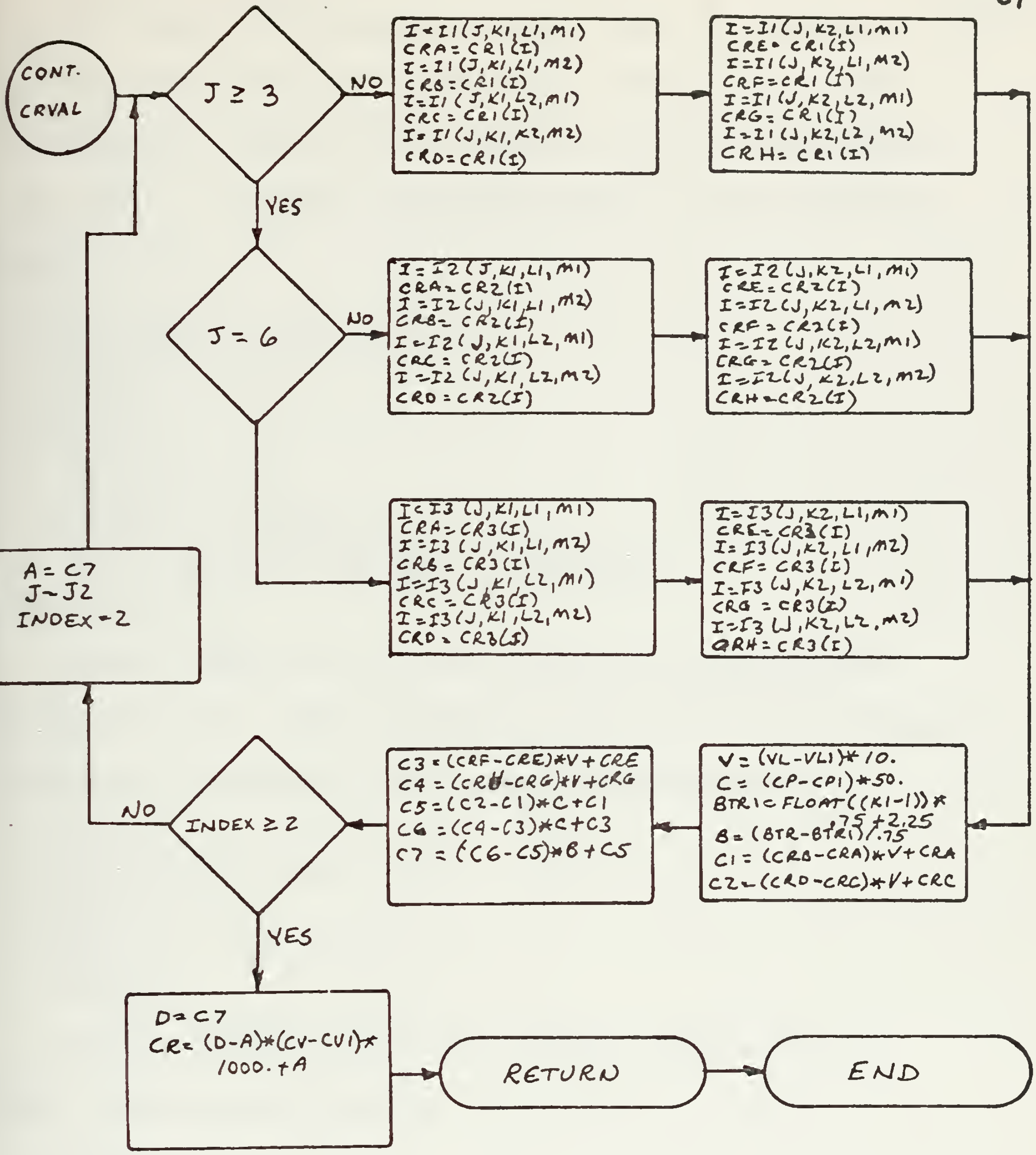

CONT. CRVAL
J ≥ 3
NO
YES
I=I1(J,K1,L1,M1)
CRA=CR1(I)
I=I1(J,K1,L1,M2)
CRB=CR1(I)
I=I1(J,K1,L2,M1)
CRC=CR1(I)
I=I1(J,K1,K2,M2)
CRD=CR1(I)
I=I1(J,K2,L1,M1)
CRE=CR1(I)
I=I1(J,K2,L1,M2)
CRF=CR1(I)
I=I1(J,K2,L2,M1)
CRG=CR1(I)
I=I1(J,K2,L2,M2)
CRH=CR1(I)
J=6
NO
I=I2(J,K1,L1,M1)
CRA=CR2(I)
I=I2(J,K1,L1,M2)
CRB=CR2(I)
I=I2(J,K1,L2,M1)
CRC=CR2(I)
I=I2(J,K1,L2,M2)
CRD=CR2(I)
I=I2(J,K2,L1,M1)
CRE=CR2(I)
I=I2(J,K2,L1,M2)
CRF=CR2(I)
I=I2(J,K2,L2,M1)
CRG=CR2(I)
I=I2(J,K2,L2,M2)
CRH=CR2(I)
I=I3(J,K1,L1,M1)
CRA=CR3(I)
I=I3(J,K1,L1,M2)
CRB=CR3(I)
I=I3(J,K1,L2,M1)
CRC=CR3(I)
I=I3(J,K1,L2,M2)
CRD=CR3(I)
I=I3(J,K2,L1,M1)
CRE=CR3(I)
I=I3(J,K2,L1,M2)
CRF=CR3(I)
I=I3(J,K2,L2,M1)
CRG=CR3(I)
I=I3(J,K2,L2,M2)
CRH=CR3(I)
A=C7
J=J2
INDEX=2
V=(VL-VL1)*10.
C=(CP-CP1)*50.
BTR1=FLOAT((K1-1))*.75+2.25
B=(BTR-BTR1)/.75
C1=(CRB-CRA)*V+CRA
C2=(CRD-CRC)*V+CRC
C3=(CRF-CRE)*V+CRE
C4=(CRH-CRG)*V+CRG
C5=(C2-C1)*C+C1
C6=(C4-C3)*C+C3
C7=(C6-C5)*B+C5
INDEX ≥ 2
NO
YES
D=C7
CR=(D-A)*(CV-CV1)*1000.+A
RETURN
END

Figure 12b

In these statements, an array index is chosen for the C_p below and above the input point. The extra 0.0001 in statement 3 and the 50.1 instead of 50 in statement 2 are used to account for small errors in the computer calculations.

```
      CV1=.005
    4 IF(CV-CV1+.00001) 5,6,6
    5 CV1=CV1-.001
      GOTO 4
   13 J1=J1-1
      CV1=CV1-.001
      GOTO 14
    6 J1=IFIX(CV1*1001.)
      IF(J1.EQ.5.AND.VL.GT.1.) GOTO 13
      IF(J1.EQ.2.AND.VL.GT.1.3) GOTO 13
   14 J2=J1+1
```

Array indices for C_v are chosen below and above the input point. The statements connected with statement 13 extend the limits of the array by extrapolation.

```
      VL1=1.9
    7 IF(VL-VL1+.0001) 8,9,9
    8 VL1=VL1-.1
      GOTO 7
    9 M1=IFIX((VL1-.4)*10.1)
      M2=M1+1
```

Again array indices are chosen, this time for speed length ratio values.

```
      J=J1
      INDEX=1
```

The value of C_v is held fixed each time through the following statements. When C_r values at each of the two C_v values have been calculated, an interpolation is done to find the C_r value at the correct C_v value.

```
   11 IF(J.GE.3) GOTO 10
      I=I1(J,K1,L1,M1)
      CRA=CR1(I)
            .
            .
```

```
        .
        .
        .
   I=I1(J,K2,L2,M2)
   CRH=CR1(I)
   GOTO 50
```

Variables CRA to CRH are used for the eight C_r values that remain when C_v is held constant. In this set of statements array CR1 is used.

```
10 IF(J.EQ.6)  GOTO 12
   I=I2(J,K1,L1,M1)
   CRA=CR2(I)
        .
        .
        .
        .
   I=I2(J,K2,L2,M2)
   CRH=CR2(I)
   GOTO 50
```

This group of statements is identical to the proceeding group except that array CR2 is used.

```
12 I=I3(J,K1,L1,M1)
   CRA=CR3(I)
        .
        .
        .
        .
   I=I3(j,K2,L2,M2)
   CRH=CR3(I)
```

Again these statements are identical with array CR3 being used.

```
50 V=(VL-VL1)*10.
   C=(CP-CP1)*50.
   BTR1=FLOAT((K1-1))*.75+2.25
   B=(BTR-BTR1)/.75
   C1=(CRB-CRA)*V+CRA
   C2=(CRD-CRC)*V+CRC
   C3=(CRF-CRE)*V+CRE
   C4=(CRH-CRG)*V+CRG
   C5=(C2-C1)*C+C1
   C6=(C4-C3)*C+C3
   C7=(C6-C5)*B+C5
```

These are the interpolation statements required to first calculate the value of C_r at the input speed length ratio, then at the input C_p and finally at the input beam to draft ratio.

```
      IF(INDEX.GE.2) GOTO 51
      A=C7
      J=J2
      INDEX=2
      GOTO 11
```

When INDEX = 1 the lower value of C_v is used in the interpolation above. The next step is to do the interpolation at the upper value of C_v. The value of C_r at the lower C_v is saved as variable A.

```
   51 D=C7
      CR=(D-A)*(CV-CV1)*1000.+A
      RETURN
      END
```

One final interpolation is performed to calculate the desired value of CR and the routine returns control to subroutine HPCALC.

3.6.4 Output for Subroutine CRVAL

The only output is the calculated value of CR which is returned as a subroutine call dummy argument.

3.6.5 Nomenclature List

All variables have the same definition as given in the MAIN program nomenclature except for the following:

A	C_r value at lower C_v value
B	fraction of BTR interval
BTR	input value of beam to draft ratio
BTR1	lower value of beam to draft ratio

C	fraction of C_p interval
C1	C_r at correct $V/\sqrt{L}$, lower BTR, lower C_p
C2	C_r at correct $V/\sqrt{L}$, lower BTR, higher C_p
C3	C_r at correct $V/\sqrt{L}$, higher BTR, lower C_p
C4	C_r at correct $V/\sqrt{L}$, higher BTR, higher C_p
C5	C_r at correct $V/\sqrt{L}$ and C_p, lower BTR
C6	C_r at correct $V/\sqrt{L}$ and C_p, higher BTR
C7	C_r at correct $V/\sqrt{L}$, C_p and BTR
CP1	lower C_p value
CR	C_r value at input point
CRA	C_r at lower $V/\sqrt{L}$, C_p and BTR
CRB	C_r at higher $V/\sqrt{L}$, lower C_p and BTR
CRC	C_r at lower $V/\sqrt{L}$ and BTR, higher C_p
CRD	C_r at higher $V/\sqrt{L}$ and C_p, lower BTR
CRE	C_r at lower $V/\sqrt{L}$ and C_p, higher BTR
CRF	C_r at higher $V/\sqrt{L}$ and BTR, lower C_p
CRG	C_r at lower $V/\sqrt{L}$, higher BTR and C_p
CRH	C_r at higher $V/\sqrt{L}$, BTR, and C_p
CV	input value of C_v
CV1	lower value of C_v
D	C_r value at upper C_v value
I	array index
INDEX	Indicates whether C_v is at lower or upper value
J	used for either J1 or J2
J1	index for lower value of C_v
J2	index for higher value of C_v
K1	index for lower value of BTR

K2	index for higher value of BTR
L1	index for lower value of C_p
L2	index for higher value of C_p
M1	index for lower value of $V/\sqrt{L}$
M2	index for higher value of $V/\sqrt{L}$
V	fraction of $V/\sqrt{L}$ interval
VL	input speed length ratio
VL1	lower value of speed length ratio

3.7 Subroutine EPLANT

3.7.1 Introduction

This routine performs two functions. The first is to estimate an average plant electrical load for use in calculating fuel requirements. The second is to size the generators. Generator size is used primarily for estimating weights, but it is also a useful output which provides information needed for beginning the preliminary design phase.

Three ships were used in developing electrical load relations. These were the 378' WHEC, the 210' WMEC, and the 150' WPB. The electrical loads for these vessels were categorized as shown in Table 1. This table also gives the loads in KW that were used.

The first two categories, electronics load and armament load, are inputs. Propulsion auxiliary load includes only equipment needed for the direct operation of the main propulsion machinery. For example, lub oil service pumps are included in this category but lub oil transfer pumps are included under other auxiliaries. Air conditioning and ventilation also includes electric heaters. Hotel is primarily galley and lighting.

Estimating relationships were developed for each of the last four categories in Table 1. If the propulsion auxiliary load is not input, a value of 1 KW is assumed for diesel plants and 71 KW for CODOG plants. Air conditioning and ventilation is calculated as a function

Table 1

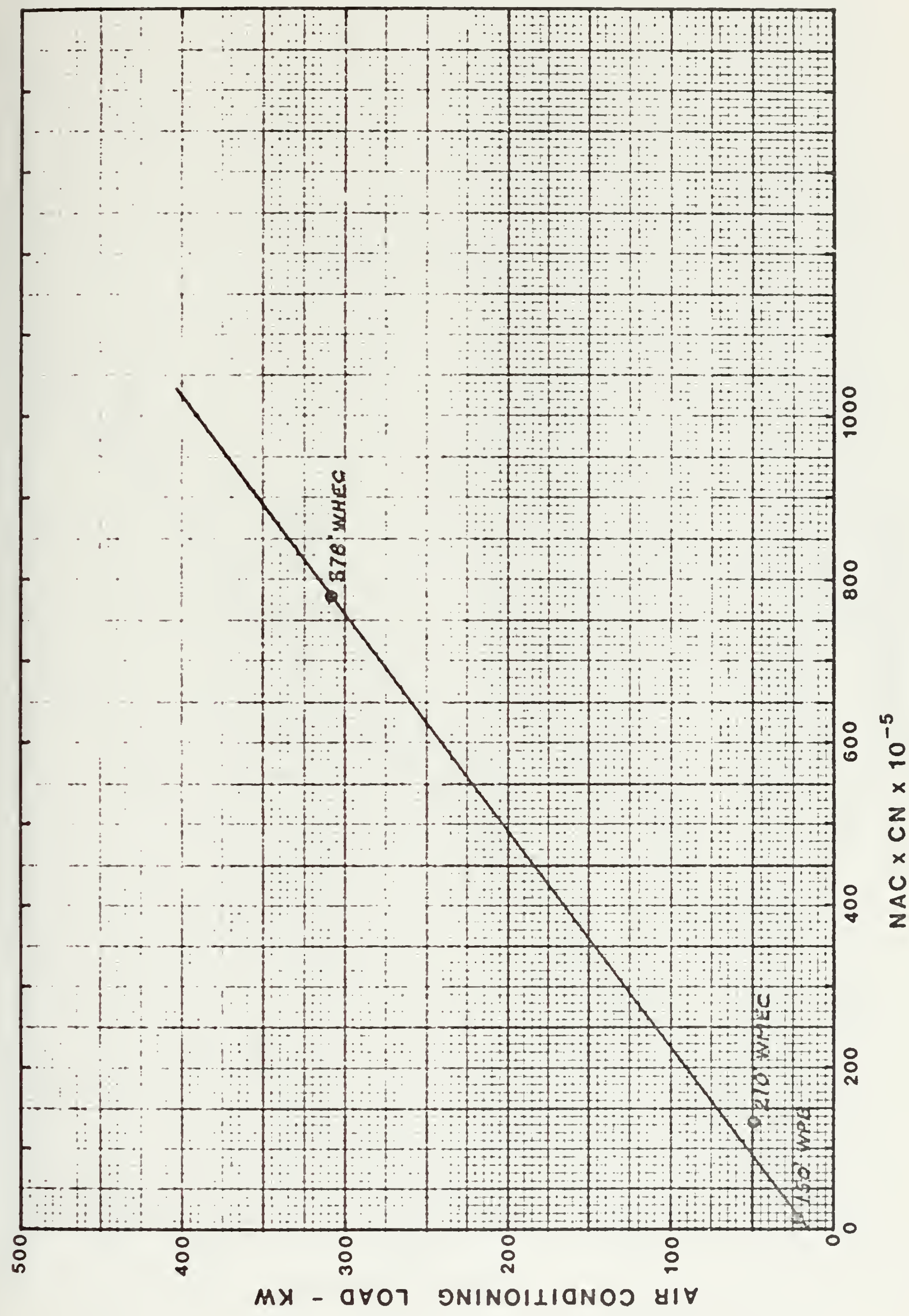
ELECTRICAL LOAD REQUIREMENTS

Electrical Load		150' WPB		210' WMEC		378' WHEC
Electronics		4.8		21.99		117.84
Armament		42.7		0.0		46.64
Propulsion Aux.		1.02		.71		71.03
Air Cond. & Vent.		21.1		49.13		308.34
Hotel		20.9		35.4		170.51
Steering gear	.54		4.48		37.38	
Aux. Machinery	18.26		40.08		70.72	
Shops	1.0		2.2		4.98	
Other Aux.(total)		19.8		46.76		113.08
Total		110.32		153.99		827.44

All loads are in KW

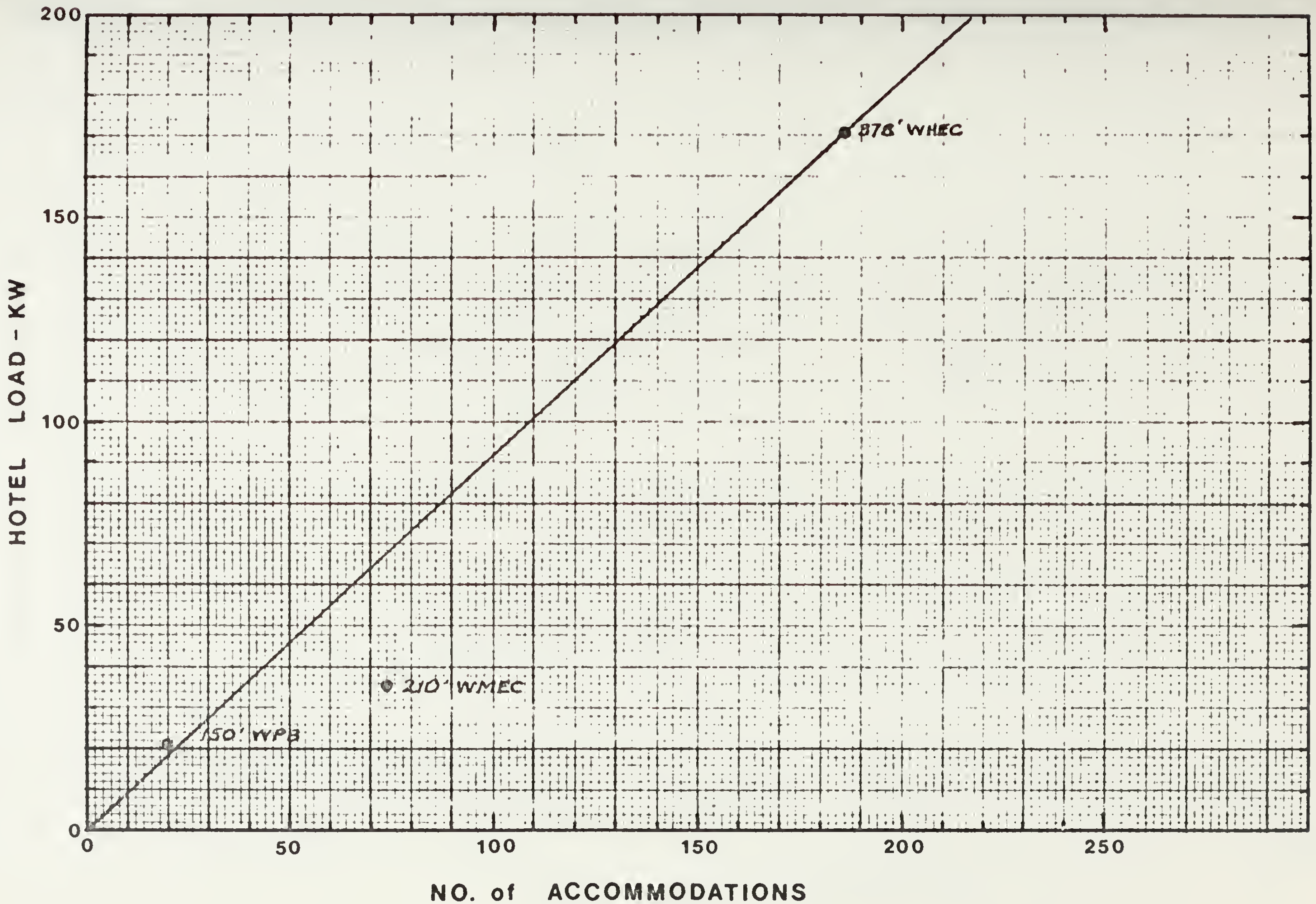
of cubic number times the number of accommodations. Hotel load is a function of the number of accommodations only. Other auxiliaries load is assumed to be a function of cubic number only. These relationships are plotted in Figures 14, 15 and 16.

The total electrical load required is equal to the sum of the six categories above with a two percent growth margin on all equipment plus a 100 percent margin on electronics. An additional 25 percent is included above the growth margin to allow for deterioration and starting loads.



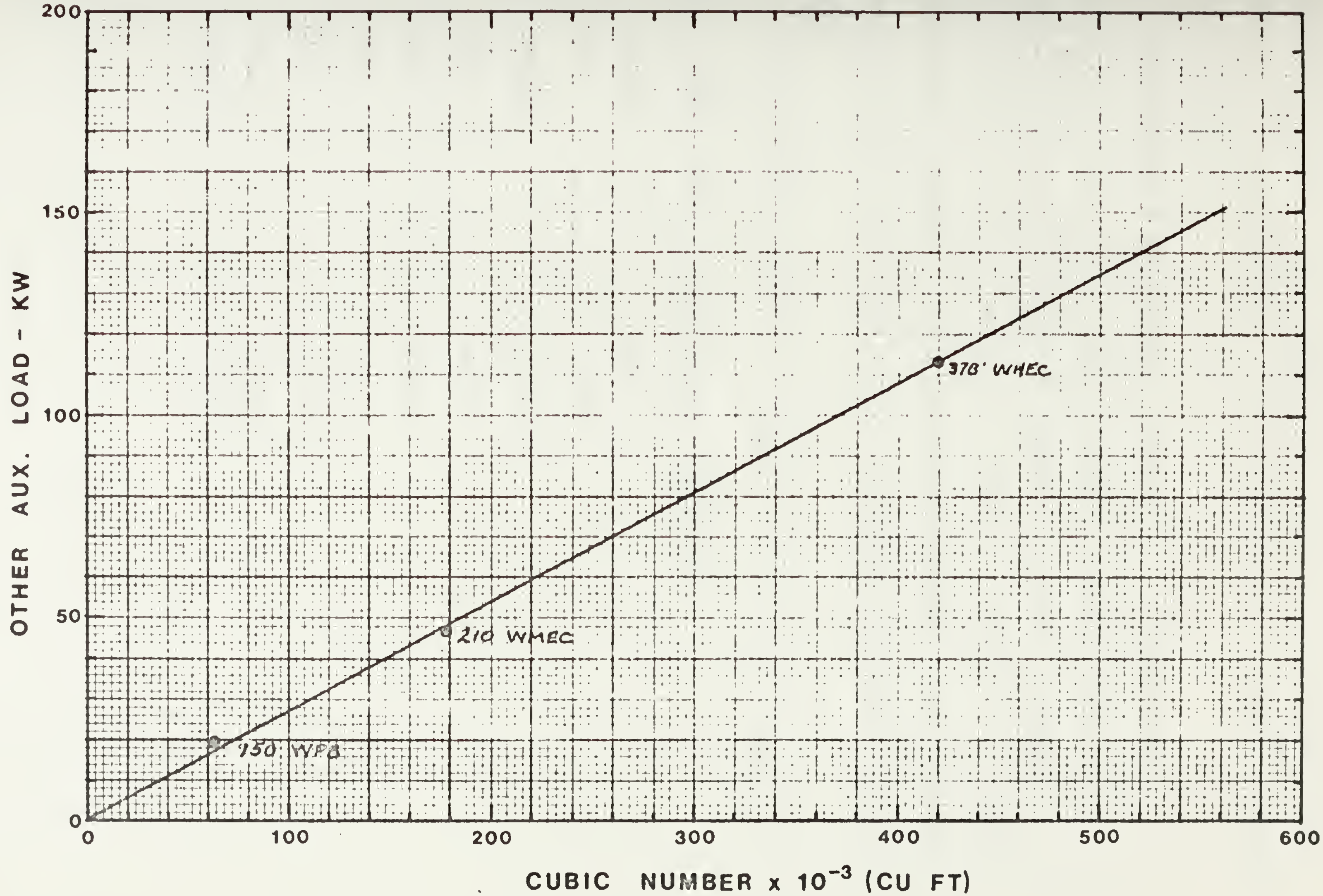
AIR CONDITIONING LOAD - KW
500
400
300
200
100
0
0
200
400
600
800
1000
NAC x CN x 10^{-5}
578' WHEC
210' WHEC
150' WPB

Figure 14



378' WHEC
210' WMEC
150' WPB
HOTEL LOAD - KW
0
50
100
150
200
250
NO. of ACCOMMODATIONS

Figure 15



OTHER AUX. LOAD - KW
200
150
100
50
0
0
100
200
300
400
500
600
378' WHEC
210 WHEC
150 WPB
CUBIC NUMBER x 10^-3 (CU FT)

Figure 16

It is assumed that three generators will be installed. Each generator is sized so as to be able to carry the full electrical load. This represents the current Coast Guard practice for new designs. Less capacity has been installed on past designs.

The smallest generator that will be installed is assumed to be 100 KW. Other possible plant sizes lie between 100 KW and 250 KW in steps of 50 KW, between 250 KW and 1000 KW in steps of 250 KW, and above 1000 KW in steps of 500 KW. The smallest generator that is able to supply the total load with the margins stated above is chosen.

A flow chart for this routine is shown in Figure 17.

3.7.2 Input List for Subroutine EPLANT

BLOAD...............LC(DD)

CN..................LC(BB)

ELOAD...............LC(DD)

JOPT................LC(CC)

MTYPE...............LC(CC)

NCPO................LC(AA)

NENL................LC(AA)

NOFF................LC(AA)

PALOAD..............LC(DD)

EPLANT SUBROUTINE
FLOW CHART

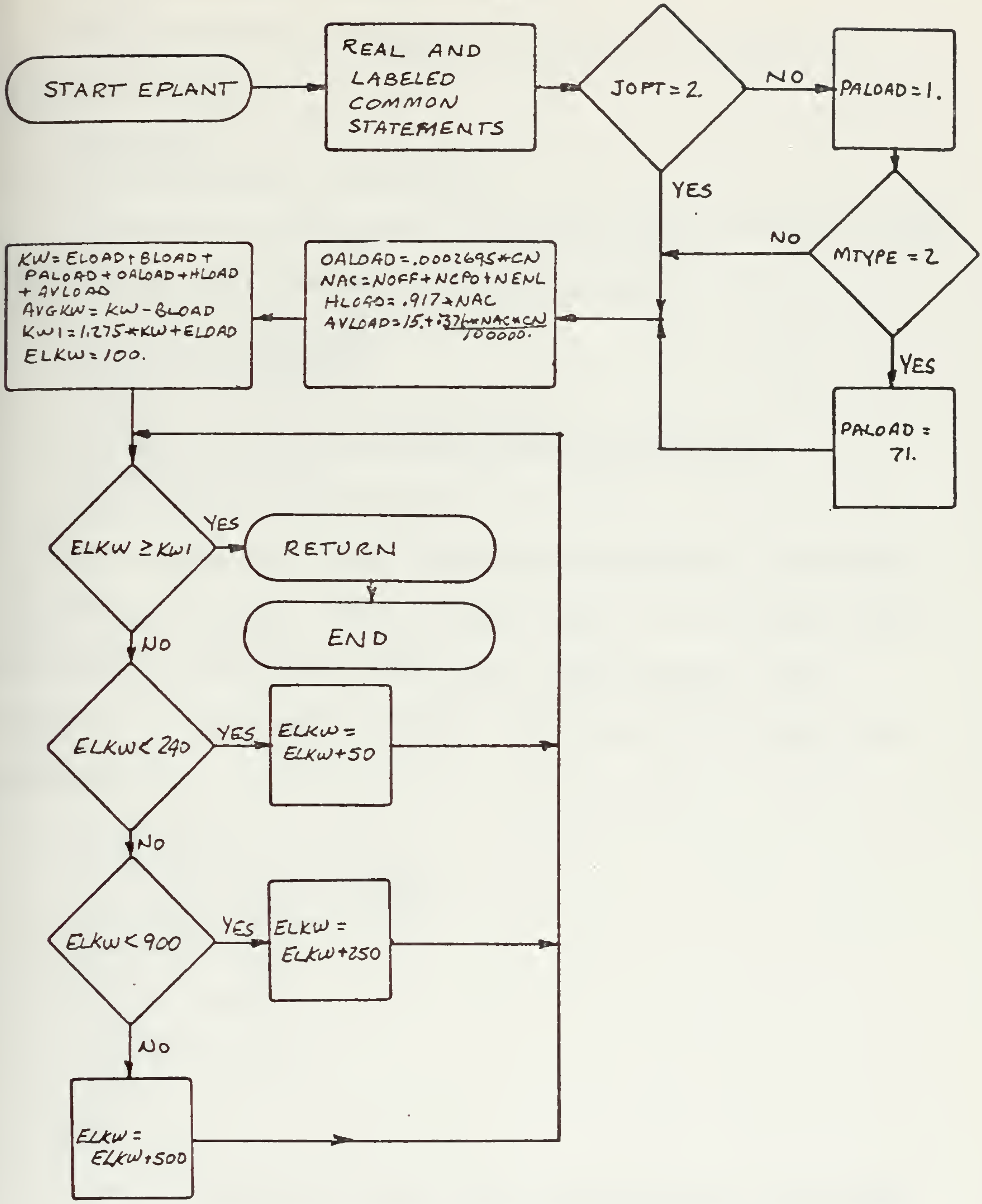


Figure 17

3.7.3 Statement Descriptions

```
IF(JOPT.EQ.2) GOTO 1
```

The estimate of PALOAD is skipped if a value is given as input.

```
PALOAD=1.
IF(MTYPE.EQ.2) PALOAD=71.
```

Propulsion auxiliaries electrical load is calculated for diesel and CODOG plants respectively.

```
1 OALOAD=.0002695*CN
  NAC=NOFF+NCPO+NENL
  HLOAD=.917*NAC
  AVLOAD=15.+.376*NAC*CN/100000.
  KW=ELOAD+BLOAD+PALOAD+OALOAD+HLOAD+AVLOAD
  AVGKW=KW-BLOAD
  KW1=1.25*(1.02*KW+ELOAD)
```

The individual load items are calculated and summed to give an estimate of the total load. The average load is taken as the total load minus the armament load. Margins are then added to the total load for sizing the generators.

```
  ELKW=100.
2 IF(ELKW.GE.KW1) GOTO 3
  IF(ELKW.LT.240.) GOT 4
  IF(ELKW.LT.900.) GOTO 5
  ELKW=ELKW+500.
  GOTO 2
4 ELKW=ELKW+50.
  GOTO 2
5 ELKW=ELKW+250.
  GOTO 2
3 RETURN
  END
```

These statements choose the generator rating, ELKW, which is the next size larger than the total load with margins.

3.7.4 Output List for Subroutine EPLANT

AVGKW................LC(DD)

ELKW.................LC(DD)

3.7.5 Nomenclature List

All variables have the same definition as given in the MAIN program nomenclature except for the following:

AVLOAD	air conditioning and ventilation load, KW
HLOAD	hotel load, KW
KW	total load without margins, KW
KW1	total load with margins, KW
NAC	number of accommodations
OALOAD	other auxiliaries load, KW
RE	same as RGEND in MAIN
SFCH	same as SFCHHP in MAIN
SFCM	same as SFCMHP in MAIN
VE	same as VEND in MAIN

3.8 Subroutine MACHLQ

3.8.1 Introduction

At this point in the program, the shaft horsepower and size of the electrical plant have been determined and the weight of fuel, lub oil and potable water can be calculated. Subroutine MACHLQ performs these calculations.' In conjunction with the fuel weight calculations, the specific fuel consumption, SFC, at endurance power is estimated.

For diesel plants it is assumed that the SFC at rated power is 0.42 lbs/shp-hr and at one half rated power is 0.46 lbs/shp-hr. A linear relation is used for other power ratios. The SFC used for CODOG plants is 0.42 if the endurance power is less than 7000 SHP. This assumes that the diesels will be sized to be at maximum power at endurance speed. If the endurance power requirements are greater than 7000 SHP, the gas turbines must be used at endurance speed. Three maximum power levels for the gas turbines are used - 25000 HP, 35000 HP and 50000 HP. At each of these horsepower levels the SFC is taken to be 0.50 lbs/shp-hr. At half power, the SFC is .595. A linear relation is used for other power levels.

If a specific machinery plant is input, the specific fuel consumptions at half and full power are given. A linear relation is used for other power levels.

The specific fuel consumption of the ship service generators is assumed to be about 0.48 lbs/shp-hr or 0.65 lbs/KW-hr. The generator fuel consumption is computed using the average electrical load.

Fuel consumption for hotel services is taken to be 0.32 lbs/man-hr. This assumes some waste heat recovery.

The lub oil requirements for diesels is assumed to be 5 tons plus 1 ton per thousand horsepower. For CODOG plants this same relationship is used for the diesel part of the plant (endurance power is used in computing the requirements). However, additional lub oil for the gas turbines is included. For the gas turbines, the oil requirements are 3.5 tons plus 1 ton per ten thousand horsepower.

Potable water requirements are taken to be 50 gal/man or 0.186 tons/man. A flow chart for this routine is shown in Figure 18.

3.8.2 Input List for Subroutine MACHLQ

AVGKW.............LC(DD)	RE.................LC(CC)
JOPT..............LC(CC)	SFCH...............LC(CC)
MTYPE.............LC(CC)	SFCM...............LC(CC)
NCPO..............LC(AA)	SHPE...............LC(CC)
NENL..............LC(AA)	SHPM...............LC(CC)
NOFF..............LC(AA)	VE.................LC(CC)

MACHLQ SUBROUTINE

FLOW CHART

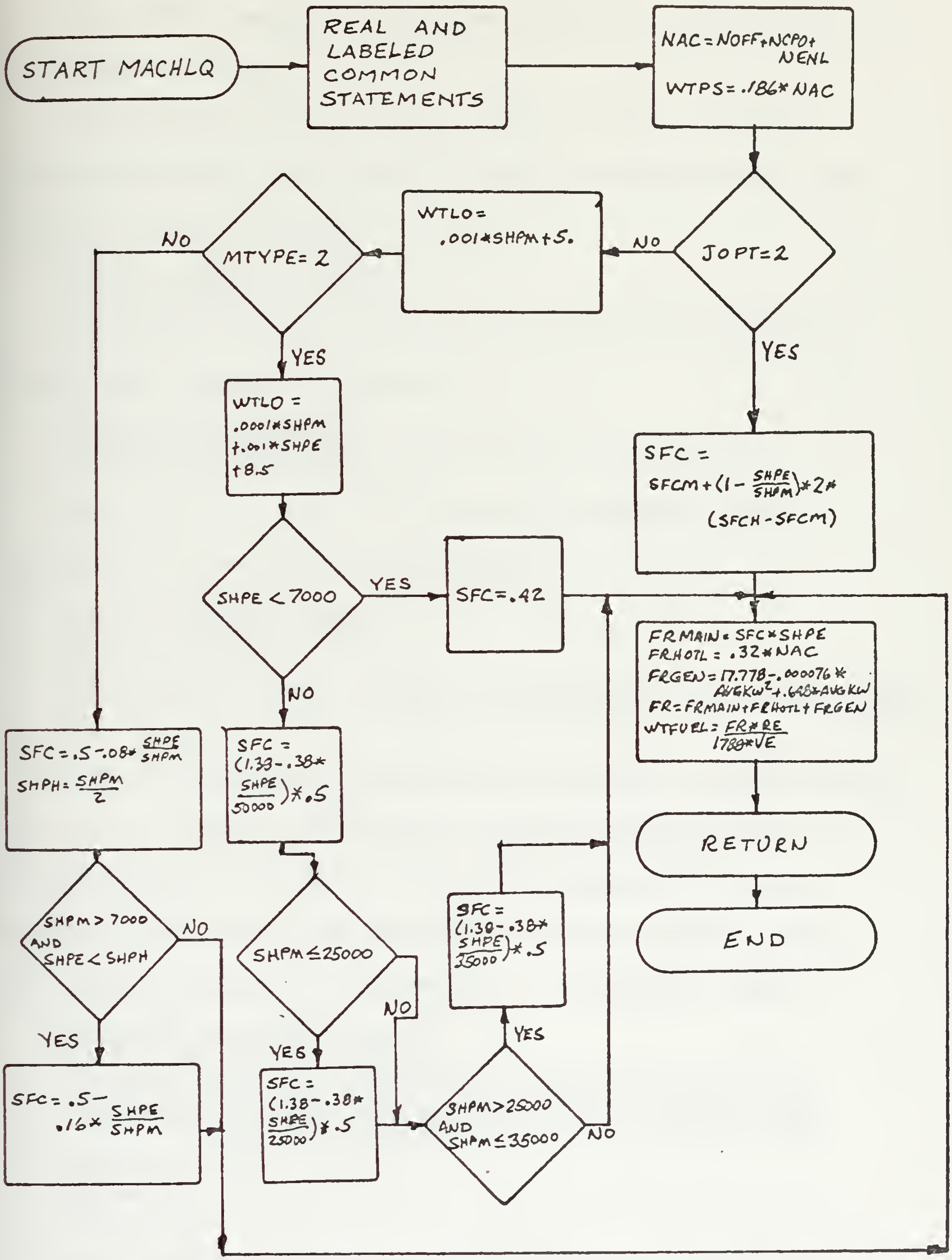


Figure 18

3.8.3 Statement Descriptions

```
NAC=NOFF+NCPO+NENL
```

The total number of accommodations is calculated.

```
WTPS=.186*NAC
```

Additional items will be added to the weight of personnel stores later but for now it includes only the weight of potable water.

```
IF(JOPT.EQ.2) GOTO 1
```

This skips the lub oil and standard SFC estimates since these values are inputs.

```
WTLO=.001*SHPM+5.
IF(MTYPE.EQ.2) WTLO=.0001*SHPM+.001*SHPE+8.5
```

The lub oil weight for diesel and CODOG plants respectively are calculated here.

```
IF(MTYPE.EQ.2) GOTO 2
SFC=.5-.08*SHPE/SHPM
SHPH=SHPM/2.
IF(SHPM.GT.7000..AND.SHPE.LT.SHPH)SFC=.5-.16*SHPE/SHPM
GOTO 3
```

These statements calculate the SFC for diesel plants. In case the shaft horsepower is greater than 7000 it is assumed that four diesels will be installed. If the endurance power is less than half of the maximum, only two diesels need be in operation at endurance speed.

```
2 IF(SHPE.LT.7000.) GOTO 4
  SFC=(1.38-.38*SHPE/50000.)*.5
  IF(SHPM.LE.25000.)SFC=(1.38-.38*SHPE/25000.)*.5
  IF(SHPM.GT.25000..AND.SHPM.LE.35000.) SFC=(1.38-
            .38*SHPE/35000.)*.5
  GOTO 3
4 SFC=.42
  GOTO 3
```

For CODOG plants the SFC is calculated using the

statements above.

```
1 SFC=SFCM+(1.-SHPE/SHPM)*2.*(SFCH-SFCM)
```

If SFCH and SFCM are input, the above linear relation is used for calculating the SFC at endurance speed.

```
3 FRMAIN=SFC*SHPE
  FRHOTL=.32*NAC
  FRGEN=.65*AVGKW
  FR=FRMAIN+FRHOTL+FRGEN
```

All of these fuel rates are in lbs/hr.

```
  WTFUEL=FR*RE/(1788.*VE)
  RETURN
  END
```

The factor 1788. is derived from:

$$\frac{2240.*(1 - F_{tp})}{F_m * F_{deg} * F_{sc}}$$

where:

F_{tp} = .05 is a tailpipe allowance

F_m = 1.03 is an extra margin

F_{deg} = 1.05 is a degradation allowance

F_{sc} = 1.10 is an allowance for sea conditions and fouling

The value 2240 converts pounds to tons.

3.8.4 Output List for Subroutine MACHLQ

WTFUEL.............LC(LL)

WTLO...............LC(LL)

WTPS...............LC(LL)

3.8.5 Nomenclature List

All variables have the same definition as given in the MAIN program nomenclature except for the following:

Nomenclature List (cont)

FR	total fuel rate in lbs/hr
FRGEN	generator fuel rate in lbs/hr
FRHOTL	hotel fuel rate in lbs/hr
FRMAIN	main engine fuel rate in lbs/hr
NAC	total number of accommodations
RE	same as RGEND in MAIN
SFC	specific fuel consumption at endurance power
SFCH	same as SFCHHP in MAIN
SFCM	same as SFCMHP in MAIN
SHPH	one half maximum shaft horsepower
VE	same as VEND in MAIN

3.9 Subroutine MBSIZE

3.9.1 Introduction

Very little data is available concerning the minimum allowable depth and length of the machinery compartment. As a result, only very simple calculations are made in this subroutine to estimate these two dimensions.

The product of length of machinery box times the maximum beam of the ship was calculated for two diesel designs, the 210' WMEC and the 150' WPB, and for one CODOG plant, the 378' WHEC. A value of about 1050 sq. ft. was obtained for both diesel designs and a value of 2300 sq. ft. was obtained using the CODOG plant. These values are divided by the beam of the ship to obtain the required engine room length in the program.

A check is also made to insure that a minimum length is not exceeded. This minimum length was taken to be 28 feet or 56 feet for diesel plants below or above 7000 BHP respectively and 45 feet for a CODOG plant.

A rough deck height approximation was derived using data from the same three vessels mentioned above. The formula used gives a deck height of about 17 feet for the 150' WPB and about 19 feet for the 210' WMEC. The deck height for all plants with horsepowers greater than 7000 is taken as 22 feet.

A flow chart for this subroutine is shown in Figure 19.

MBSIZE SUBROUTINE
FLOW CHART

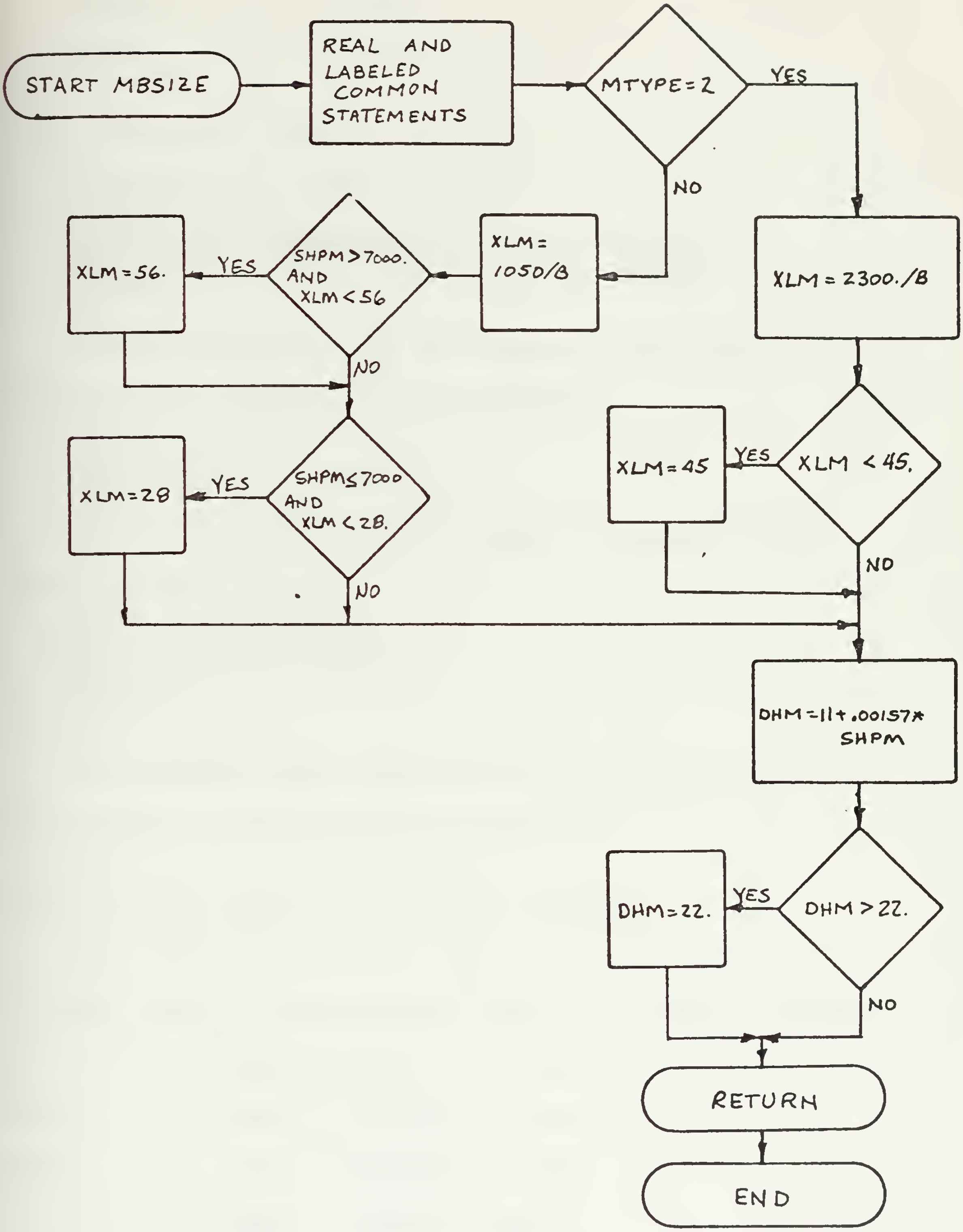


Figure 19

3.9.2 Input List for MBSIZE Subroutine

B.................SCDA

MTYPE...........LC(CC)

SHPM............LC(CC)

3.9.3 Statement Descriptions

```
      IF(MTYPE.EQ.2) GOTO 1
      XLM=1050./B
      IF(SHPM.GT.7000..AND.XLM.LT.56.) XLM=56.
      IF(SHPM.LE.7000..AND.XLM.LT.28.) XLM=28.
      GOTO 2
```

These statements set the engine room length for diesel plants. (MTYPE = 1 for diesels)

```
    1 XLM=2300./B
      IF(XLM.LT.45.) XLM=45.
```

These statements set the engine room length for CODOG plants.

```
    2 DHM=11.+.00157*SHPM
      IF(DHM.GT.22.) DHM=22.
      RETURN
      END
```

The minimum deck height, which is the same for both plant types, is set by these statements.

3.9.4 Output List for Subroutine MBSIZE

All variables have the same definition as given in the MAIN program nomenclature except for the following:

RE	same as RGEND in MAIN
SFCH	same as SFCHHP in MAIN
SFCM	same as SFCMHP in MAIN
VE	same as VEND in MAIN

3.10 Subroutine VOLUME

3.10.1 Introduction

Many of the ships designed today are volume rather than weight limited. Because of this it is important that a ship synthesis model determine a balance between required and available volume as well as between weight and displacement. Subroutine VOLUME performs this function in the cutter model.

The dimensions of the hull below the load waterline are determined in subroutine UWDIM. Only the sheer line, deckhouse volume and the length of raised deck, if any, remain to be determined to define the volume available in the ship. The enclosed volume of the hull and deckhouse will be completely determined by these variables since the waterplane coefficient is calculated in subroutine UWDIM and since the general shape of the hull is implied by the estimating relationships used in the model.

Deckhouse volume is constrained primarily by stability considerations and by external deck area requirements. If the deckhouse becomes too high, it will not be possible to make the vessel stable. Also a certain amount of free deck area is required in nearly all designs, restricting the horizontal spreading of the deckhouse. At the other extreme, the ship may have excessive stability if too small a deckhouse is installed.

These deckhouse volume restrictions have been included

in the cutter model by restricting deckhouse size to be within the limits of past practice. Both an upper and a lower limit are placed on the size of the deckhouse as shown in Figure 20. The deckhouse volume of Coast Guard vessels has been generally greater than that of Navy designs. Upper and lower limits of $0.00150 \times L^3$ and $0.001 \times L^3$, respectively, are used in the Navy's destroyer model. This difference is probably due to the fact that the Navy requires more external deck area for armament.

The deckhouse volumes shown in Figure 20 do not include uptakes. It is assumed that sufficient additional area is available for uptakes since uptake area was excluded from the data points also. However, it is important to check a design be sketching a layout for the external decks and the superstructure before acceptance.

The volume in the hull is also estimated in VOLUME. The underwater volume is already available. The first step in determining the above water hull volume is the development of an acceptable sheer line. This step is performed by subroutine SHEER and is discussed in conjunction with that routine.

Once the sheer line and with it the average freeboard have been estimated, the above water volume is found by multiplying the area of the waterplane by the average freeboard and by a factor to account for flare. The total volume in the hull is the sum of the above and below water volumes.

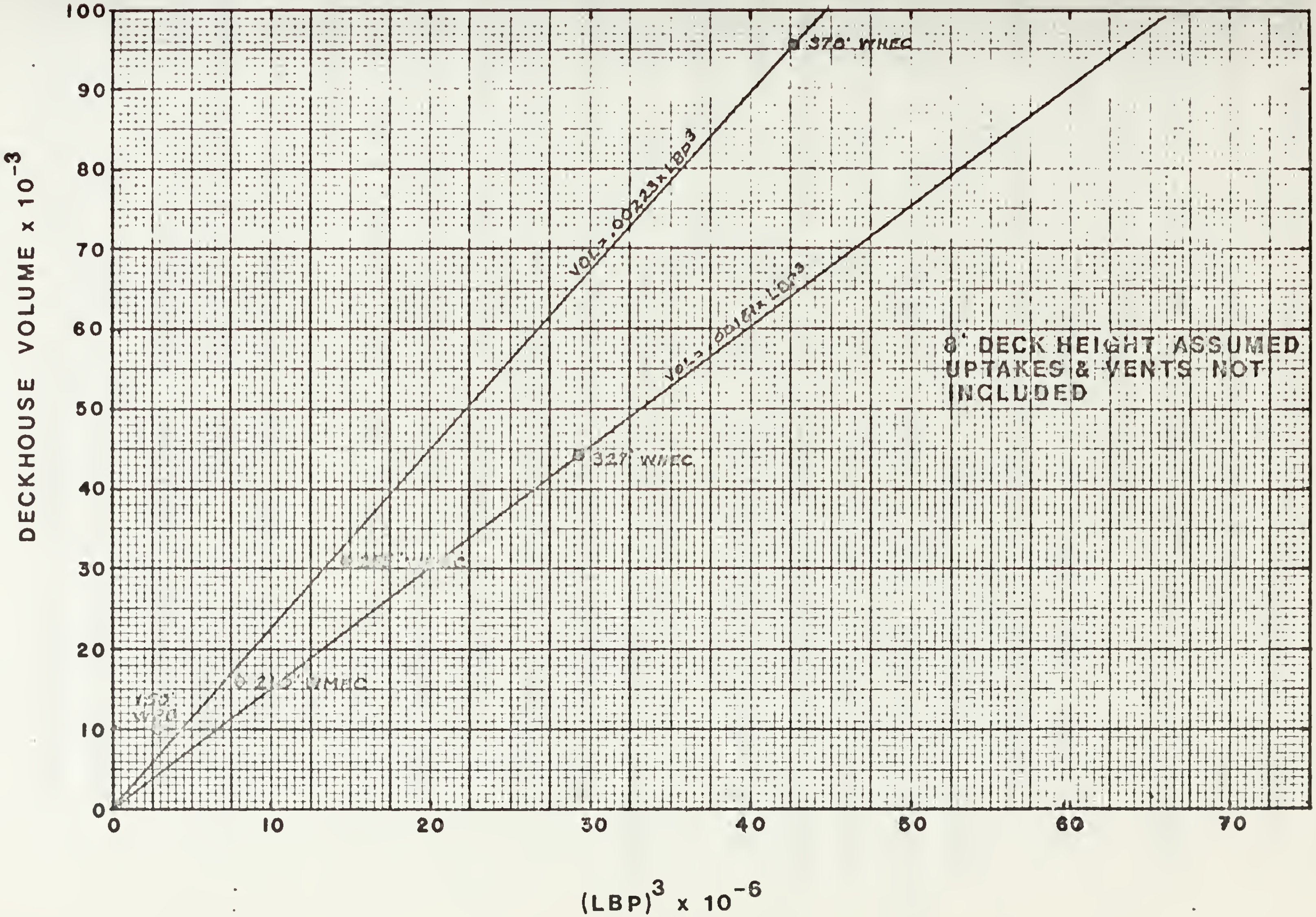

DECKHOUSE VOLUME x 10^{-3}
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
$(LBP)^3 \times 10^{-6}$
370' WHEC
VOL = .00223 x LBP^3
327' WHEC
215' WMEC
8' DECK HEIGHT ASSUMED
UPTAKES & VENTS NOT
INCLUDED

Figure 20

This total hull volume includes the volume to the main deck only. The hull volume cannot be reduced below this size but a raised deck can be added to increase the volume of the hull. For vessels of the size of Coast Guard cutters it is impractical to add more than one raised deck. Also the deckhouse size can be varied somewhat to change the available volume.

Required hull volume is broken down into three categories. These are the machinery box, tankage volume and arrangements volume. The object of subroutine VOLUME is to alter the available volume so that there is sufficient space for each of the three categories of required volume. The model assumes that all tankage volume and the machinery box volume are in the hull. The deckhouse contains only arrangements volume.

The machinery box size is the first category estimated. This volume is found by multiplying the midships area by the length of the machinery box and by a machinery box prismatic coefficient. Machinery box volume is subtracted from the available hull volume to the main deck leaving a volume which can be used for tankage and arrangements.

Some of the remaining volume cannot be used for arrangements because of hull shape. The next step is to estimate the fraction of the remaining volume that can be used only for tankage. This is the minimum tankage volume for the ship. If less tankage is required for

the liquids that must be carried, the excess volume must be used for voids or cofferdams since it cannot be converted into machinery box space or arrangements volume. If more tankage is required than this minimum, some of the arrangements volume must be used for tankage.

The weights of all the liquids which must be carried are calculated in subroutine MACHLQ. In VOLUME, these weights are converted to volumes and added together. A twenty percent allowance is added to this figure to account for required cofferdams and voids. The volume required for liquids is then compared to the minimum tankage volume to determine the amount of arrangements volume, if any, that is required for tankage.

All of the volume remaining in the hull after tankage volume and machinery box volume have been subtracted can be used for arrangements. The entire superstructure volume is also available for arrangements. Arrangements space requirements are more commonly given as areas rather than as volumes, so the next step is to convert the available arrangements volume to an available arrangements area. For the deckhouse this is a simple task since the deckhouse is nearly wall sided. The volume is divided by the deckheight of 8.5 feet to find the area. For the hull no such simple procedure is possible because of hull curvature.

The Navy performed extensive work on this problem while developing their destroyer model, DD07. This work

was made use of in the cutter model not only for the arrangements area formulation but also for the flare factor, machinery box prismatic coefficient and tankage volume fraction estimates discussed earlier. The relationships used in the cutter model were taken directly from the original notes[8] of Mr. Jim Mills who was largely responsible for the development work done by the Navy.

The major deviation between the cutter model and the destroyer model lies in the engine room location. The destroyer model assumes that the engine room is centered at amidships but Coast Guard practice usually places the engine room aft of amidships. No correction is made for this difference and the output produced for test runs with existing ships indicates that there is little effect.

By using the Navy's formula, the arrangements area in the hull can be calculated. This area plus the area of the deckhouse must be compared to the area required for all the ship's functions plus the area specified as input. The area required for ship's functions such as stores area, living area and auxiliary machinery area, are estimated in the cutter model based on past practice.

Data was obtained by measuring the areas of five past designs and assigning the areas to various categories. This data is summarized in Table 2. Linear relationships were developed from this data as shown in Figures 21 through 25. Berthing and sanitary areas are based on minimum Coast Guard standards. The area required for

CATEGORY	378 WHEC	327 WHEC	255 WHEC	210 WMEC	150 WPB
Office Spaces	493	465	347	130	65
Messing Facilities	2713	2348	1379	1452	339
Crew Special	725	609	717	324	32
Officer Staterooms	1157	1338	966	567	187
Officer Sanitary	243	133	120	193	30
CPO Staterooms	1040	364	336	283	110
CPO Sanitary	250	100	-	75	27
Crew Berthing	3641	2655	2568	1658	375
Crew Sanitary	716	444	492	384	90
CO Stateroom & Cabin	697	511	273	406	-
CO Pantry	58	128	22	-	-
Commissary Stores	600	724	531	480	35
Other Stores	3015	2354	2397	1294	435
Workshops	1161	818	752	544	-
Passages	2567	2588	2138	739	229
Repair Lockers	148	18	97	110	-
Steering Gear & Windlass	736	548	645	270	294
Chain Locker	47	30	36	42	16
A/C & Fan Spaces	369	324	39	165	-
I.C. & Gyro Room	312	143	232	180	-
Aux. Machinery Spaces	1860	1874	414	820	543
Uptakes (Hull)	462	1216	64	-	-
Pilothouse, Chartroom & C.I.C.	1125	856	521	422	300
Sub total	24135	20588	15086	10538	3107
EXTRAS					
Crew Recreation Rooms	1445	-	682	-	71
Cargo & Flume Tanks	1219	249	-	-	241
Electronics & Stores	1618	775	1206	319	157
Armament & Stores	844	822	730	280	-
Balloon Shelters	512	156	120	-	-
Mission Offices & Labs	746	336	482	-	-
Mission Workshops	-	-	70	105	-
Bow Thruster	344	-	-	-	-
Total	30863	22926	18376	11242	3576

Table 2

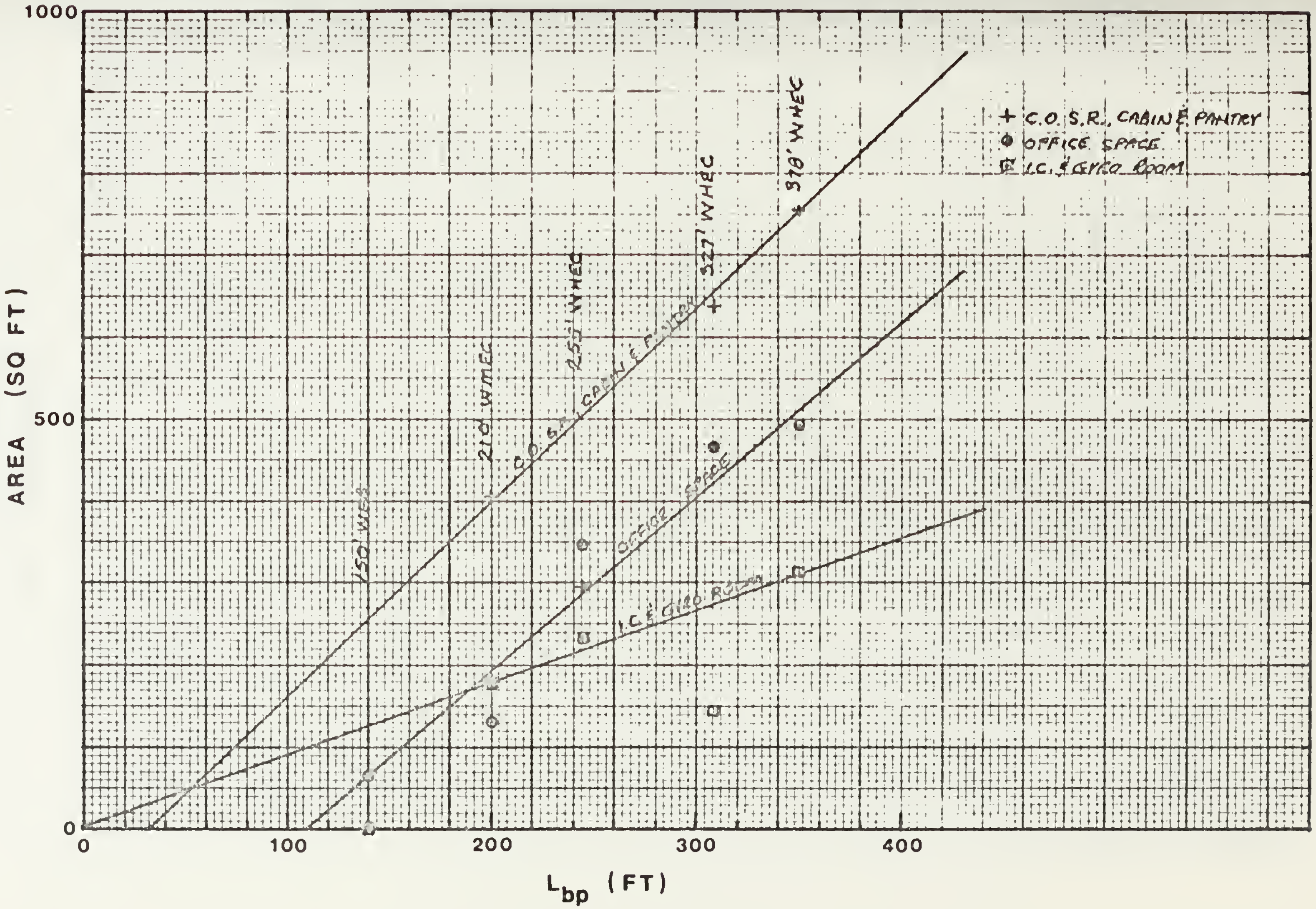

+ C.O. S.R., CABIN & PANTRY
OFFICE SPACE
I.C. & GYRO ROOM
150' WEB
210' WMEC
255' WHEC
327' WHEC
378' WHEC
OFFICE SPACE
I.C. & GYRO ROOM
1000
500
0
100
200
300
400
AREA (SQ FT)
L_{bp} (FT)

Figure 21

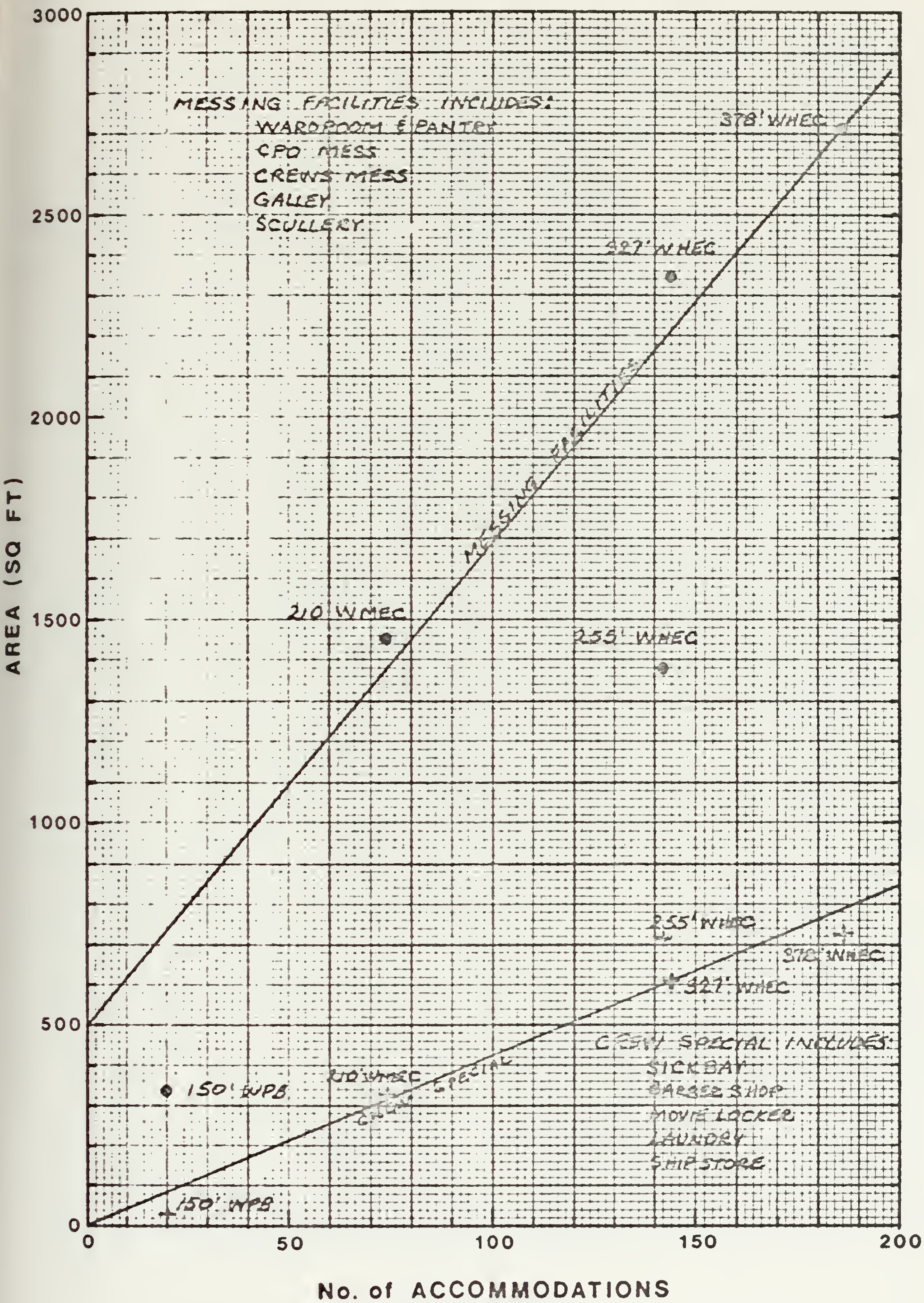
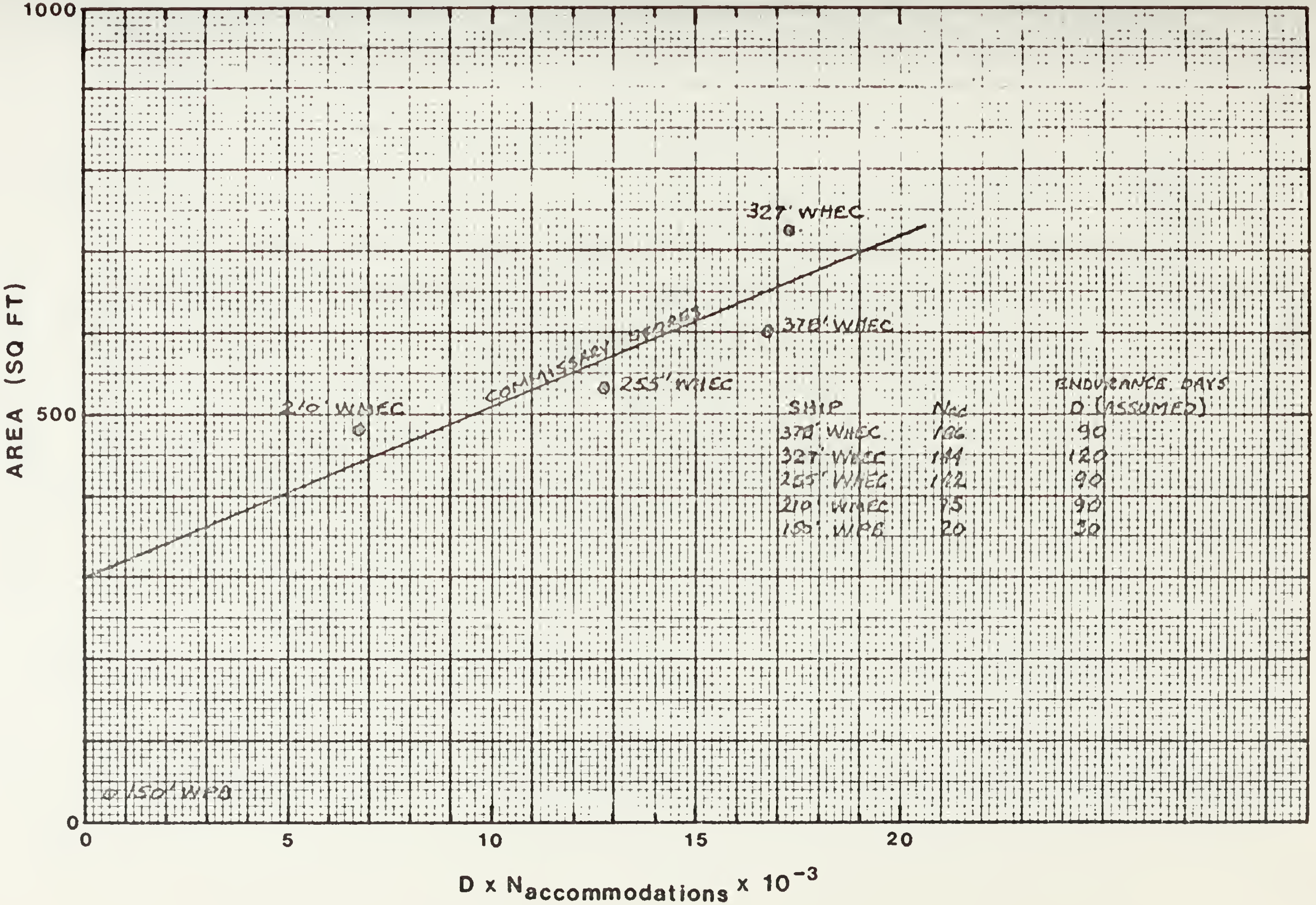

MESSING FACILITIES INCLUDES:
WARDROOM & PANTRY
CPO MESS
CREWS MESS
GALLEY
SCULLERY
378' WHEC
327' WHEC
MESSING FACILITIES
210' WMEC
255' WHEC
255' WHEC
378' WHEC
327' WHEC
CREW SPECIAL INCLUDES:
SICKBAY
BARBER SHOP
MOVIE LOCKER
LAUNDRY
SHIP STORE
210' WMEC
CREW SPECIAL
150' WPB
150' WPB
AREA (SQ FT)
No. of ACCOMMODATIONS

Figure 22



AREA (SQ FT)
1000
500
0
0
5
10
15
20
D x $N_{accommodations} \times 10^{-3}$
327' WHEC
378' WHEC
255' WHEC
210' WHEC
150' WPB
COMMISSARY STORES
SHIP | N_{acc} | ENDURANCE DAYS D (ASSUMED)
378' WHEC | 106 | 90
327' WHEC | 144 | 120
255' WHEC | 122 | 90
210' WHEC | 75 | 90
150' WPB | 20 | 30

Figure 23

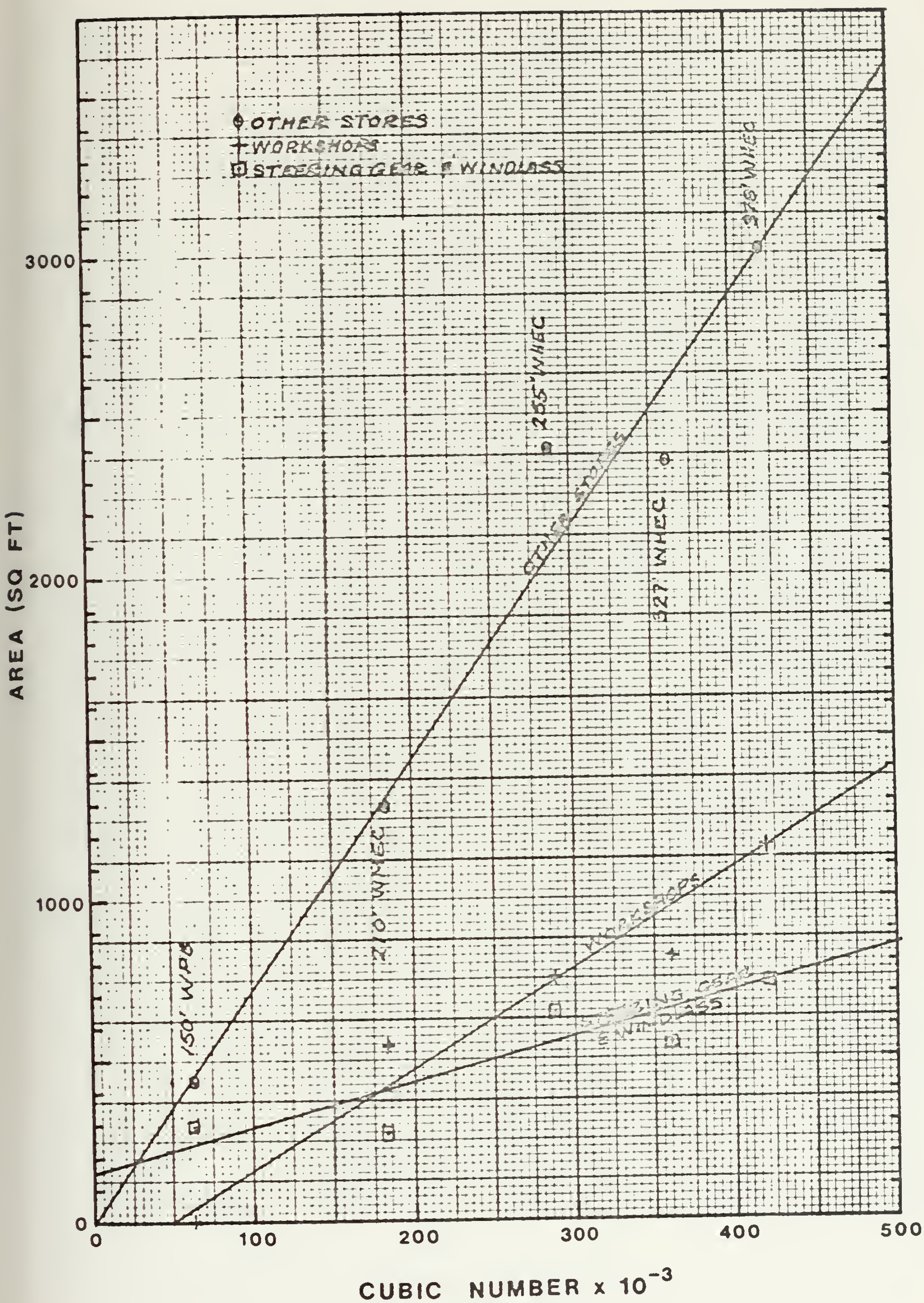

OTHER STORES
WORKSHOPS
STEERING GEAR & WINDLASS
AREA (SQ FT)
3000
2000
1000
0
0
100
200
300
400
500
150' WPB
210' WMEC
255' WHEC
327 WHEC
378' WHEC
OTHER STORES
WORKSHOPS
STEERING GEAR & WINDLASS
CUBIC NUMBER x 10^{-3}

Figure 24

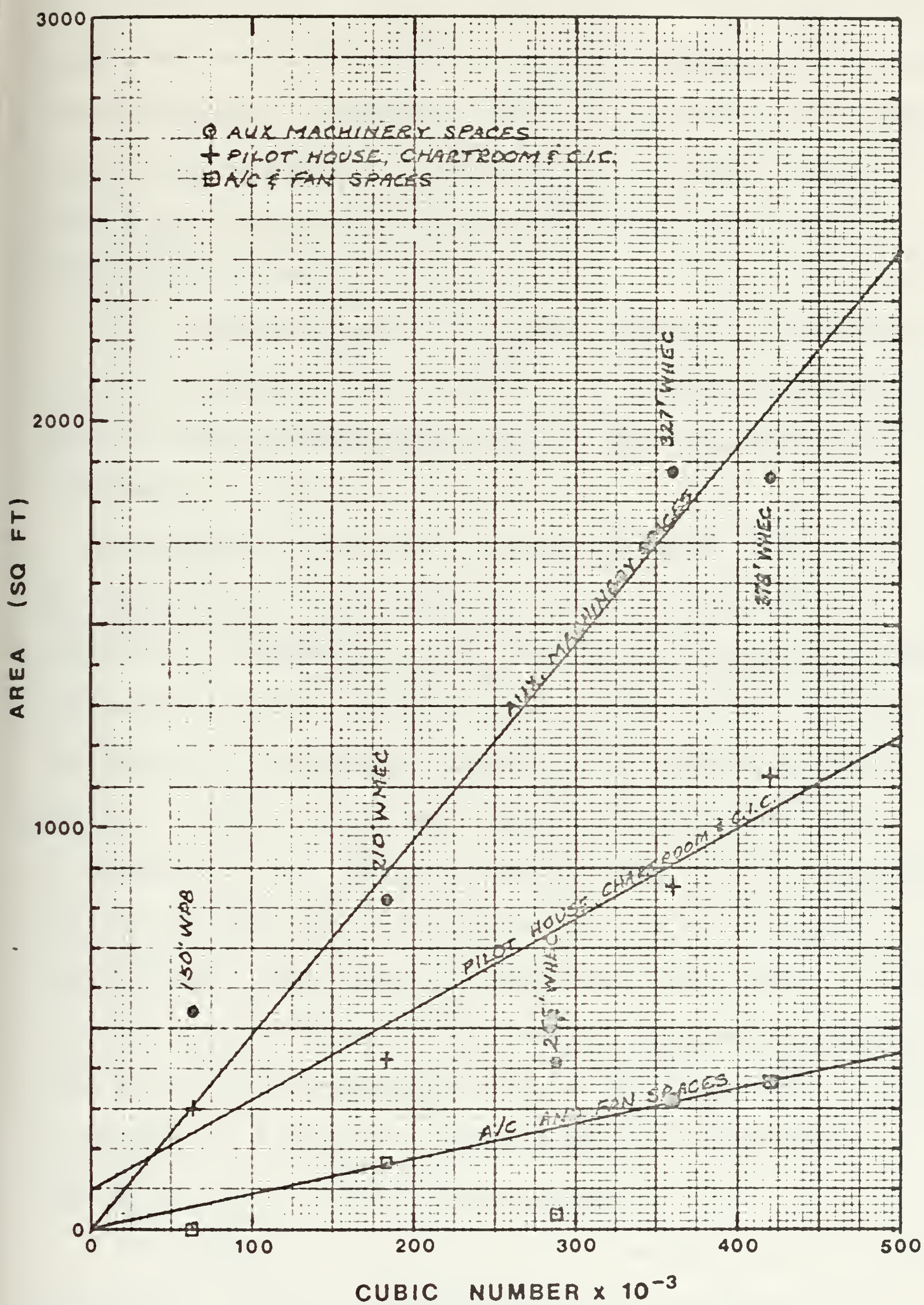

3000
2000
1000
0
AREA (SQ FT)
0
100
200
300
400
500
CUBIC NUMBER x 10^{-3}
AUX MACHINERY SPACES
PILOT HOUSE, CHARTROOM & C.I.C.
A/C & FAN SPACES
150' WPB
210' WMEC
327' WHEC
378' WHEC
AUX. MACHINERY SPACES
PILOT HOUSE, CHARTROOM & C.I.C.
A/C AND FAN SPACES

Figure 25

repair lockers is taken as a constant 100 square feet. The area for chain lockers as 40 square feet and the area for uptakes in the hull as either 65 or 460 square feet depending on whether diesels or gas turbines, respectively, are installed. A constant value of nine percent of the total area is assumed for passages. Passages ranged from 6.84 to 13.17 percent of the total area on the five designs used.

All of the required areas are summed to determine the total required area. This area is then compared to the available arrangements area in the hull and superstructure.

Comparisons are made in the following order. First, the arrangements area required to be located in the deckhouse is compared to the area of the largest allowable deckhouse. If the required area exceeds that available, the design is infeasible and an error message must be printed. Next, the total required arrangements area is compared to the total available area. If the required area is the smaller, the deckhouse size is decreased. The deckhouse size used is either the size which balances the area requirements or the smallest allowable deckhouse size or the area required to be in the deckhouse, whichever is greatest. Should the total required area exceed that available a raised deck is added.

The length of raised deck is determined by an iterative procedure. On each iteration the area required to be

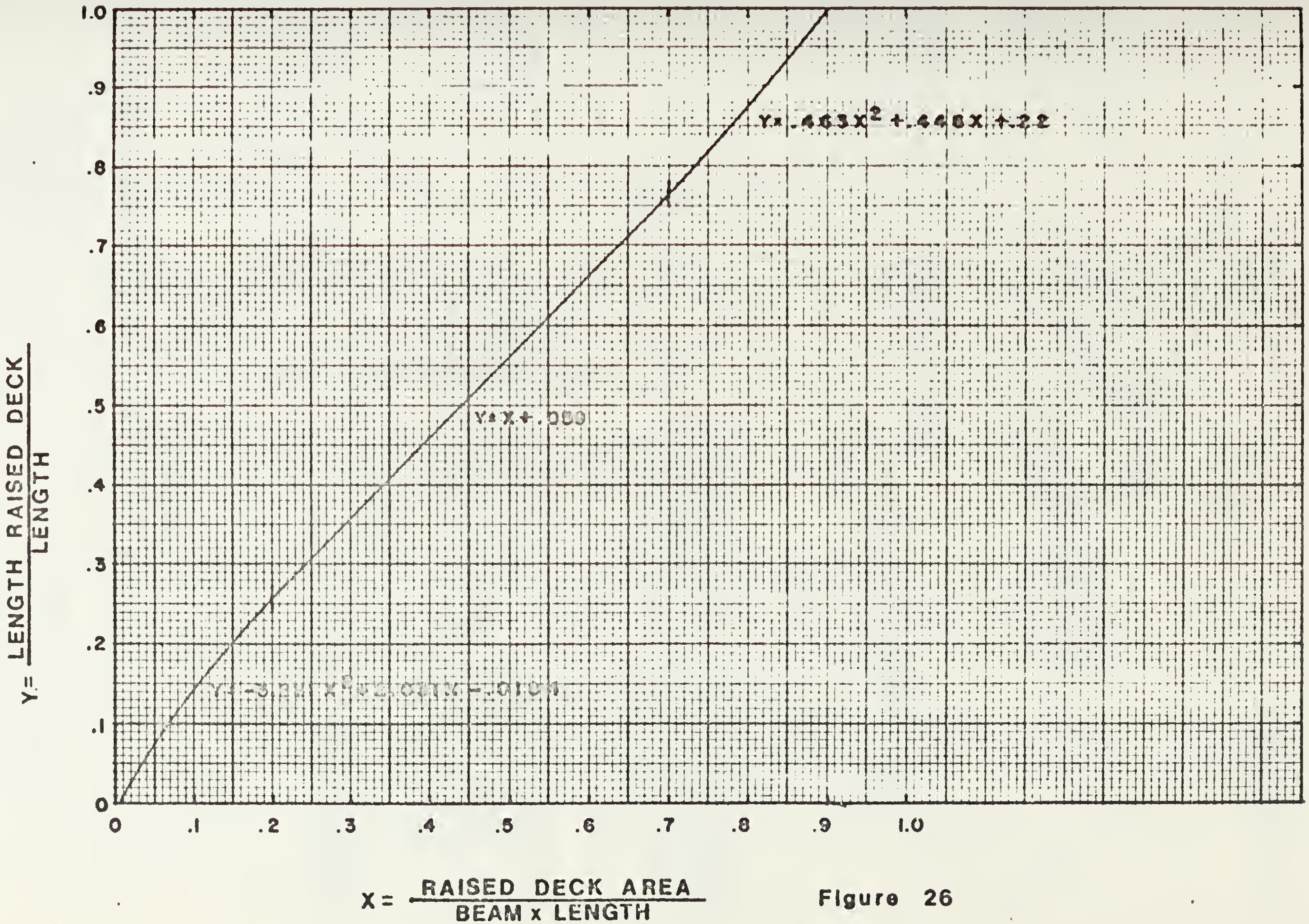
included in the raised deck is computed and the curve shown in Figure 26 is used to convert the area to a raised deck length. This curve is based on the main deck of a 378' WHEC. The iteration continues until two successive iterations fall within 5 percent of the length of the ship or until twenty iterations is reached. In the later case the design is ruled infeasible. A check is also made to insure that the raised deck length does not exceed the length of the ship.

If the raised deck length lies between 0.4 and 0.6 times the length of the ship, the raised deck is extended to 0.6 times the length of the ship.

A flow chart for this routine is shown in Figures 27a and 27b.

3.10.2 Input List for Subroutine VOLUME

AREADH	LC(BB)	LEN	LC(BB)
AREAHL	LC(BB)	LMB	LC(JJ)
B	LC(GG)	MTYPE	LC(CC)
CP	LC(GG)	NCPO	LC(AA)
CWP	LC(GG)	NENL	LC(AA)
CX	LC(GG)	NOFF	LC(AA)
D	LC(AA)	WACFUL	LC(LL)
DMB	LC(JJ)	WTFUEL	LC(LL)
H	LC(GG)	WTLO	LC(LL)
JOPT	LC(CC)	WTPS	LC(LL)



1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
Y= LENGTH RAISED DECK / LENGTH
Y= .463X² + .448X + .22
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
X = RAISED DECK AREA / BEAM x LENGTH

Figure 26

VOLUME SUBROUTINE FLOW CHART

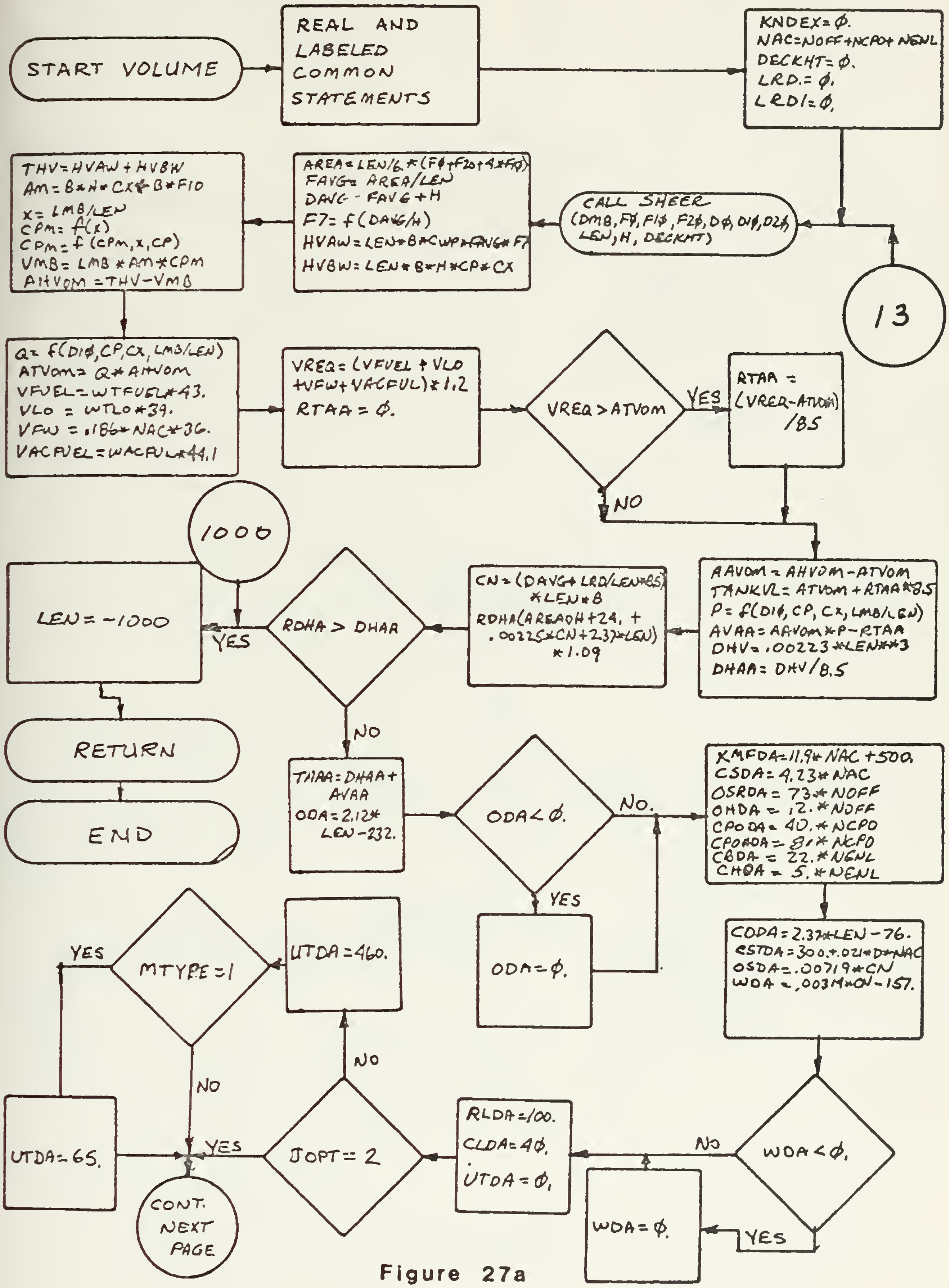


Figure 27a

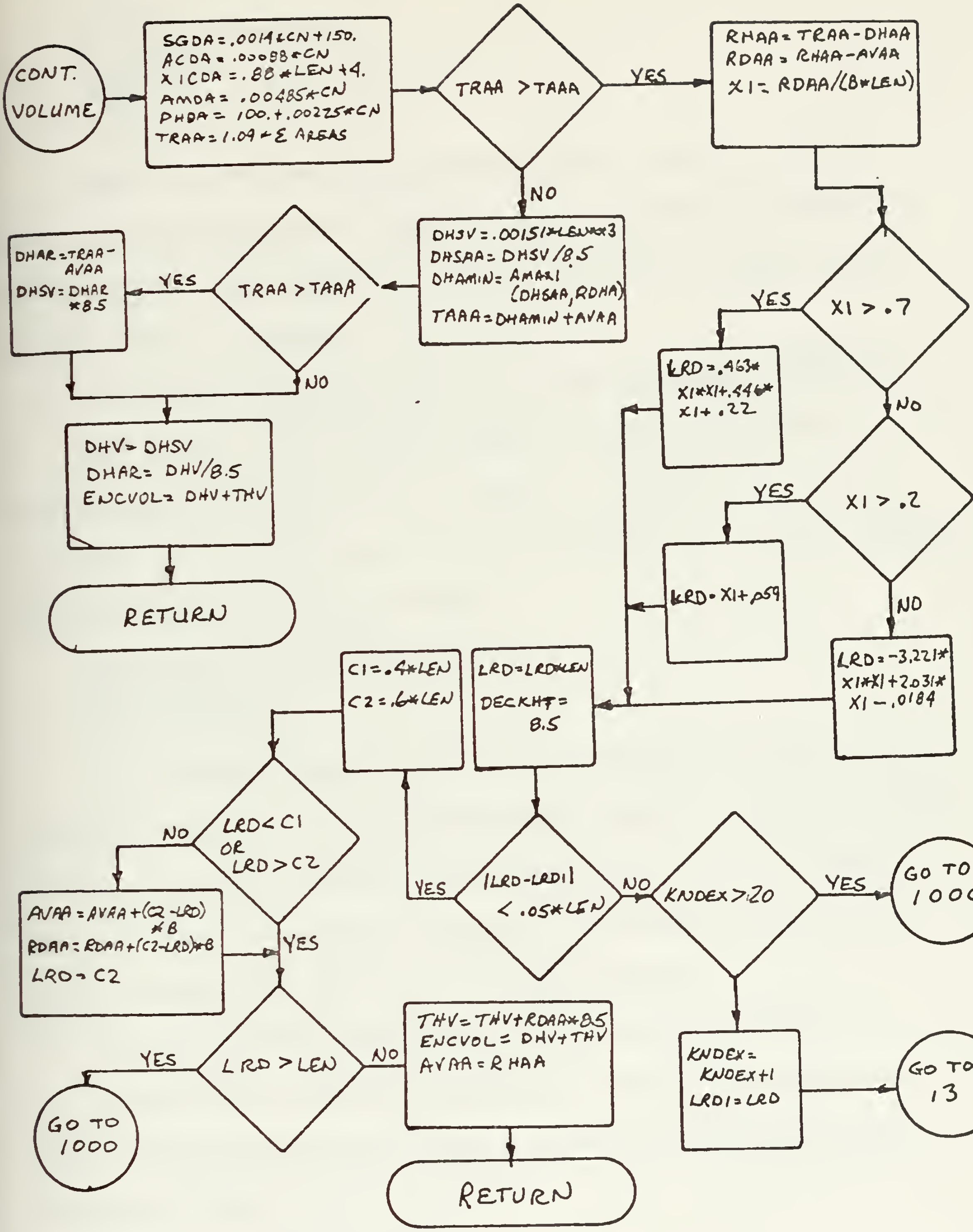

CONT. VOLUME
SGDA=.0014*CN+150.
ACDA=.00088*CN
XICDA=.88*LEN+4.
AMDA=.00485*CN
PHDA=100.+.00225*CN
TRAA=1.09*Σ AREAS
TRAA > TAAA
YES
NO
RHAA=TRAA-DHAA
RDAA=RHAA-AVAA
X1=RDAA/(B*LEN)
DHSV=.00151*LEN**3
DHSAA=DHSV/8.5
DHAMIN=AMAX1 (DHSAA,RDHA)
TAAA=DHAMIN+AVAA
TRAA > TAAA
DHAR=TRAA-AVAA
DHSV=DHAR*8.5
DHV=DHSV
DHAR=DHV/8.5
ENCVOL=DHV+THV
RETURN
X1 > .7
LRD=.463*X1*X1+.446*X1+.22
X1 > .2
LRD=X1+.059
LRD=-3.221*X1*X1+2.031*X1-.0184
C1=.4*LEN
C2=.6*LEN
LRD=LRD*LEN
DECKHT=8.5
LRD<C1 OR LRD>C2
AVAA=AVAA+(C2-LRD)*B
RDAA=RDAA+(C2-LRD)*B
LRD=C2
|LRD-LRD1| < .05*LEN
KNDEX>20
GO TO 1000
LRD > LEN
THV=THV+RDAA*8.5
ENCVOL=DHV+THV
AVAA=RHAA
KNDEX=KNDEX+1
LRD1=LRD
GO TO 13

Figure 27b

3.10.3 Statement Descriptions

```
KNDEX=0
NAC=NOFF+NCPO+NENL
DECKHT=0.
LRD=0.
LRD1=0.
```

KNDEX is an iteration counter used for the raised deck length iteration. The variable DECKHT is explained in the SHEER subroutine. The two values of raised deck length start at zero.

```
13 CALL SHEER(DMB,F0,F10,F20,D0,D10,D20,LEN,H,DECKHT)
```

The sheer line of the vessel is defined by the freeboard at stations 0, 10, and 20. These values are returned as F0, F10, and F20 respectively. The associated hull depths are also returned.

```
AREA=LEN/6.*(F0+F20+4*F10)
FAVG=AREA/LEN
DAVG=FAVG+H
```

The average depth is calculated using the projected lateral area. A better estimation could be made by using the local beam to weight the freeboard values but this was not done.because the value of F7 which corrects for flare is based on the above average depth.

```
F7=-.018828*(DAVG/H)**2+.18098*DAVG/H+.714599
```

This is the flare correction factor. The formula used was taken from the Navy's work in developing their destroyer model.

```
HVAW=LEN*B*CWP*FAVG*F7
HVBW=LEN*B*H*CP*CX
THV=HVAW+HVBW
```

The total hull volume to the main deck is calculated

by these statements.

```
AM=B*H*CX+B*F10
X=LMB/LEN
CPM=-.525*X*X+.055*X+.99675
CPM=CPM+3.2*X*X*(CP-.6)
VMB=LMB*AM*CPM
AHVOM=THV-VMB
```

The volume of the machinery box and the remaining available hull volume are calculated in these statements. The formula for CPM has been taken from the Navy's work and applies to machinery boxes centered about amidships.

```
Q=(-.9037115+.2139727*D10-1.38263E-2*D10**2+
     4.008058E-4*D10**3-5.489481E-6*D10**4+
     2.892153E-8*D10**5)*CP/.58*CX/.814*
     (1.11*LMB/LEN+.667)
ATVOM=Q*AHVOM
VFUEL=WTFUEL*43.
VLO=WTLO*39.
VFW=.186*NAC*36.
VACFUL=WACFUL*44.1
VREQ=(VFUEL+VLO+VFW+VACFUL)*1.2
RTAA=0.
IF(VREQ.GT.ATVOM) RTAA=(VREQ-ATVOM)/8.5
AAVOM=AHVOM-ATVOM
TANKVL=ATVOM+RTAA*8.5
```

The available volume which can be used only for tankage and the required tankage volume are calculated and compared in these statements. The formula for Q was again taken from the destroyer model work. The required tankage arrangements area is calculated if the required tankage volume is in excess of that available.

```
P=(6.51041E-7*D10**3-7.851484E-5*D10**2+3.438375E-3*
     D10+.0530399)*(.191*CP+.8893)*(.191*CX+.8445)*
     (-.105*LMB/LEN+1.0315)
AVAA=AAVOM*P-RTAA
```

The available arrangements volume is converted to an available arrangements area again using a Navy developed formula.

```
      DHV=.00223*LEN**3
      DHAA=DHV/8.5
      CN=(DAVG+LRD/LEN*8.5)*LEN*B
      RDHA=(AREADH+24.+.00225*CN+2.37*LEN)*1.09
      IF(RDHA.GT.DHAA) GOTO 1000
      TAAA=DHAA+AVAA
```

The area in the largest acceptable deckhouse is compared to the area required to be in the deckhouse.' If the required area is smaller, the program continues. If not, an error message is printed. The areas required to be in the deckhouse include the input areas plus the commanding officers cabin and the pilothouse. An allowance is also made for passageways.

```
      ODA=2.12*LEN-232.
              .
              .
              .
      PHDA=100.+.00225*CN
```

The statements above and those included between them are used to calculate the required deck areas.

```
      TRAA=1.09*(AREADH+AREAHL+ODA+XMFDA+CSDA+OSRDA+OHDA+
          CPODA+CPOHDA+CBDA+CHDA+CODA+CSTDA+CSDA+WDA+
          RLDA+CLDA+UTDA+SGDA+ACDA+XICDA+AMDA+PHDA)
      IF(TRAA.GT.TAAA) GOTO 10
```

The total required arrangements area is computed and compared with the area available in the hull to the main deck plus the largest acceptable deckhouse. A decision is then made to either make the deckhouse smaller or to add a raised deck.

```
      DHSV=.00151*LEN**3
      DHSAA=DHSV/8.5
      DHAMIN=AMAX1(DHSAA,RDHA)
      TAAA=DHAMIN+AVAA
      IF(TRAA.GT.TAAA) GOTO 11
   12 DHV=DHSV
      DHAA=DHV/8.5
```

```
   ENCVOL=DHV+THV
   RETURN
11 DHAR=TRAA-AVAA
   DHSV=DHAR*8.5
   GOTO 12
```

These statements compute the deckhouse size required if the deckhouse is to be made smaller. First, the larger value of the minimum deckhouse size or the required deckhouse area is chosen and added to the hull voulume. This new available area is then compared to the total required area. If the available area is still the greater, the difference is excess area that cannot be reduced since the minimum size hull and deckhouse are already being used. If more than the minimum deckhouse size is required a calculation is made to balance the total required area and the total available area.

```
10 RHAA=TRAA-DHAA
   RDAA=RHAA-AVAA
   X1=RDAA/(B*LEN)
   IF(X1.GT..7) GOTO 1
   IF(X1.GT..2) GOTO 2
   LRD=-3.22*X1*X1+2.031*X1-.0184
   GOTO 3
 1 LRD=.463*X1*X1+.446*X1+.22
   GOTO 3
 2 LRD=X1+.059
 3 LRD=LRD*LEN
   DECKHT=8.5
   IF(ABS(LRD-LRD1).LT..05*LEN) GOTO 15
   IF(KNDEX.GT.20) GOTO 1000
   KNDEX=KNDEX+1
   LRD1=LRD
   GOTO 13
```

If more area is required than is available in the largest deckhouse plus the hull to the main deck, a raised deck is added. The assumption is made that a ship with the maximum deckhouse size will result in the least

displacement. This is probably valid so long as an aluminum deckhouse is used.

The length of raised deck required is computed in the above statements. The new raised deck length is then compared to the former estimate, LRD1. If the two do not agree within five percent of the length of the ship a new iteration is made. A default counter has been included to keep the computer from being caught in a nonconverging loop.

```
 15 C1=.4*LEN
    C2=.6*LEN
    IF(LRD.LT.C1.OR.LRD.GT.C2) GOTO 4
    AVAA=AVAA+(C2-LRD)*B
    RDAA=RDAA+(C2-LRD)*B
    LRD=C2
```

These statements check to see if the raised deck length falls within 0.4 to 0.6 times the ship length. If so the calculated values are corrected so that the raised deck length is equal to 0.6 times the ship length.

```
  4 IF(LRD.GT.LEN) GOTO 1000
    THV=THV+RDAA*8.5
    ENCVOL=DHV+THV
    RETURN
```

A check is first made to insure that a raised deck length longer than the length of the ship is not required. A corrected total volume is then calculated and the program returns.

```
1000 LEN=-1000.
     RETURN
     END
```

Statement 1000 is a default option warning subroutine XECUTE to print an error message.

3.10.4 Output List for Subroutine VOLUME

ACDA..............LC(PP)	DHV..............LC(BB)
AMDA..............LC(PP)	ENCVOL...........LC(BB)
AVAA..............LC(PP)	LRD..............LC(JJ)
CBDA..............LC(PP)	ODA..............LC(PP)
CHDA..............LC(PP)	OHDA.............LC(PP)
CLDA..............LC(PP)	OSDA.............LC(PP)
CN................LC(BB)	OSRDA............LC(PP)
CODA..............LC(PP)	PHDA.............LC(PP)
CPODA.............LC(PP)	RLDA.............LC(PP)
CPOHDA............LC(PP)	SGDA.............LC(PP)
CSDA..............LC(PP)	TANKVL...........LC(PP)
CSTDA.............LC(PP)	UTDA.............LC(PP)
D0................LC(II)	VMB..............LC(PP)
D10...............LC(II)	WDA..............LC(PP)
D20...............LC(II)	XICDA............LC(PP)
DAVG..............LC(BB)	XMFDA............LC(PP)
DHAA..............LC(PP)	

3.10.5 Nomenclature List

The definition of all variables is the same as given in the MAIN program nomenclature except for the following:

AAVOM	available arrangements volume in hull, cu ft
ACDA	A/C & ventilation deck area, sq ft
AHVOM	available hull volume, cu ft
AM	cross sectional area amidships, sq ft
AMDA	aux. machinery spaces deck area, sq ft
AREA	projected lateral area above water, sq ft

ATVOM	available tankage volume, cu ft
AVAA	available arrangements area in hull, sq ft
C1	0.4 x length, ft
C2	0.6 x length, ft
CBDA	crews berthing deck area, sq ft
CHDA	crews heads deck area, sq ft
CLDA	chain locker deck area, sq ft
CODA	C.O. S.R., Cabin & pantry deck area, sq ft
CPM	machinery box prismatic coefficient
CPODA	CPO S.R. deck area, sq ft
CPOHDA	CPO heads deck area, sq ft
CSDA	crew special deck area, sq ft
CSTDA	commissary stores deck area, sq ft
D	same as ENDDAY in MAIN
D0	depth at F.P., ft
D10	depth at amidships, ft
D20	depth at A.P., ft
DECKHT	height of raised deck, ft
DHAA	deckhouse arrangements area, sq ft
DHAMIN	minimum deckhouse area, sq ft
DHAR	deckhouse area required, sq ft
DHSAA	smallest deckhouse arrangements area, sq ft
DHSV	smallest deckhouse volume, cu ft
DMB	same as DHM in MAIN
F0	freeboard at F.P., ft
F7	flare factor
F10	freeboard at amidships, ft

F20	freeboard at A.P.,ft
FAVG	average freeboard, ft
HVAW	hull volume above waterline, cu ft
HVBW	hull volume below waterline, cu ft
KNDEX	counter
LMB	same as XLM in MAIN
LRD1	used to store LRD value
NAC	number of accommodations.
ODA	office deck area, sq ft
OHDA	officer heads deck area, sq ft
OSDA	other stores deck area, sq ft
OSRDA	officer staterooms deck area, sq ft
P	coefficient
PHDA	pilothouse, chartroom & CIC deck area, sq ft
Q	coefficient
RDAA	raised deck arrangements area, sq ft
RDHA	area required to be in deckhouse, sq ft
RE	same as RGEND in MAIN
RHAA	required hull arrangements area, sq ft
RLDA	repair locker deck area, sq ft
RTAA	required tankage arrangements area, sq ft
SFCH	same as SFCHHP in MAIN
SFCM	same as SFCMHP in MAIN
SGDA	steering gear & windlass deck area, sq ft
TAAA	total available arrangements area, sq ft
TANKVL	tankage volume, cu ft

THV	total hull volume, cu ft
TRAA	total required arrangements area, sq ft
UTDA	uptake deck area in hull, sq ft
VACFUL	volume of aircraft fuel, cu ft
VE	same as VEND in MAIN
VFUEL	volume of ships fuel, cu ft
VFW	volume potable water, cu ft
VLO	volume of lub oil, cu ft
VMB	volume of machinery box, cu ft
VREQ	required tankage volume, cu ft
WDA	workshops deck area, sq ft
X	LMB/LEN
X1	RDAA/(B*LEN)
XICDA	I.C. & gyro room deck area, sq ft
XMFDA	messing facilities deck area, sq ft

3.11 Subroutine SHEER

3.11.1 Introduction

Subroutine SHEER selects an appropriate sheer line by specifying the freeboard at the forward perpendicular, amidships, and at the after perpendicular. This sheer line must satisfy a number of criteria.

First, there must be sufficient depth amidships to accommodate the engine room. The depth amidships must also be sufficient to insure adequate structural strength. A minimum value of L/16 is used. Because Coast Guard vessels normally have engine rooms aft of amidships, a slightly greater depth amidships is used rather than the machinery box depth. This accounts for the drop in the sheer line aft of amidships.

The next criterion which must be satisfied is adequate freeboard at the forward and after perpendiculars. Navy derived formulas were used. These formulas give the minimum acceptable freeboard based on a deck wetness criterion.

Once independent determinations of freeboard at the forward and after perpendiculars and at amidships are made, a check is required to insure that a reasonable sheer line can be drawn between the three. Data was obtained from past designs and from the standard merchant ship sheer curves. This data was nondimensionalized by subtracting the freeboard amidships from the other freeboard values and then dividing by the length of the ship.

The resulting curves are plotted in Figure 28.

The sheer line is assumed to be practical if the forward sheer fraction lies between 0.01 and 0.03 and the after sheer fraction lies between 0.001 and 0.0075. If this is not the case, one or more of the freeboard values is adjusted until the criterion is satisfied.

If a raised deck is added to the hull, a new sheer line is calculated. It is assumed that the required freeboard of the main deck at the forward perpendicular can be one deck height or 8.5 feet below that required by the deck wetness criterion. This will result in a flattened sheer line as is common for raised deck vessels.

A flow chart for this routine is shown in Figure 29.

3.11.2 Input List for Subroutine SHEER

DMB..............SCDA   H...............SCDA

LEN..............SCDA   DECKHT..........SCDA

3.11.3 Statement Descriptions

```
D10=.0025*LEN+DMB
IF(D10.LT.LEN/16) D10=LEN/16.
```

The minimum depth amidships is selected by these statements.

```
F0=1.011827*(100.*H/LEN)-.000636215*LEN+2.780649
F0=LEN*F0/100.
F0=F0-DECKHT
D0=F0+H
```

The minimum depth at the forward perpendicular is selected here.

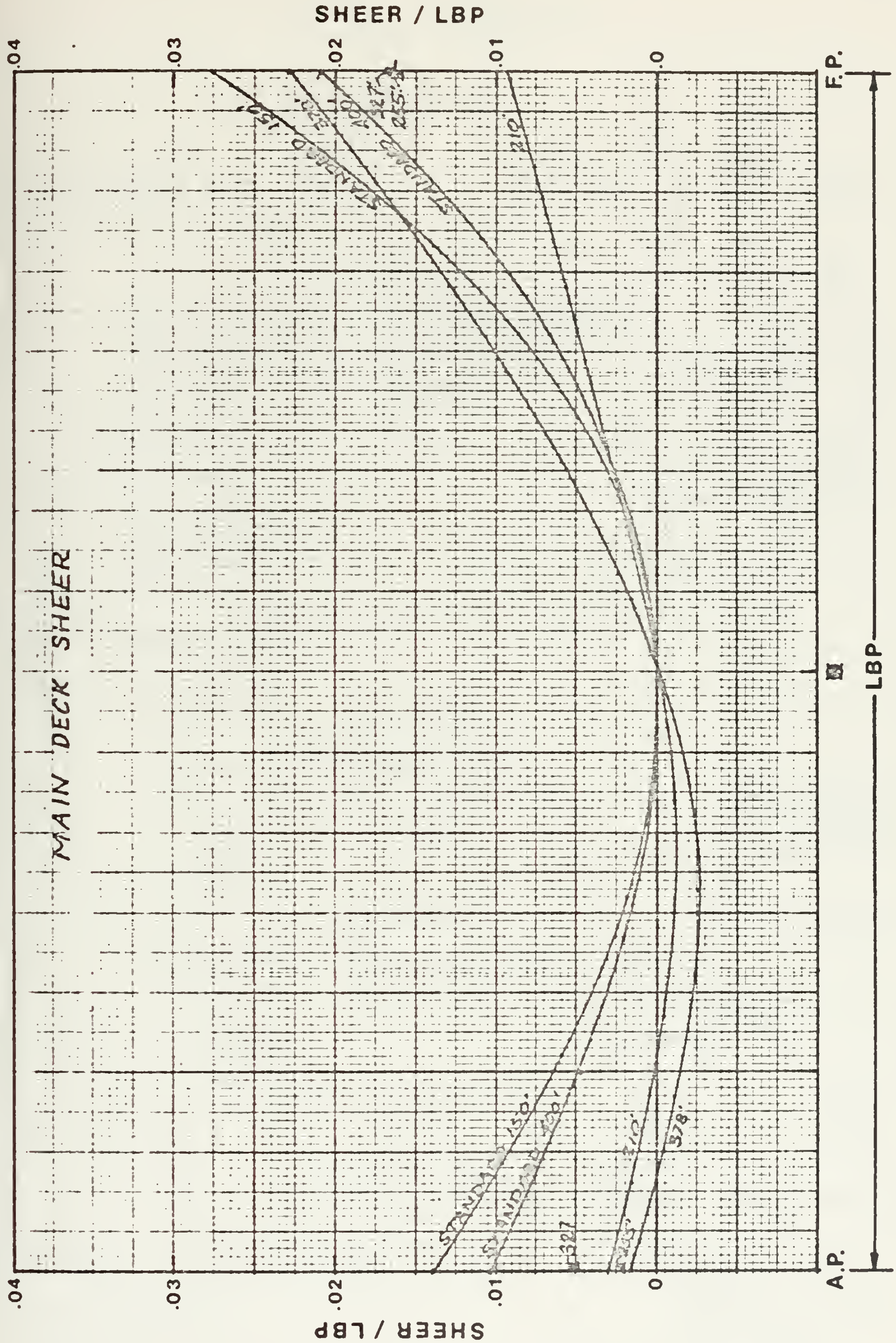

SHEER / LBP
.04
.03
.02
.01
0
MAIN DECK SHEER
STANDARD 150'
STANDARD 400'
310'
378'
327'
F.P.
A.P.
LBP
SHEER / LBP

Figure 28

SHEER SUBROUTINE
FLOW CHART

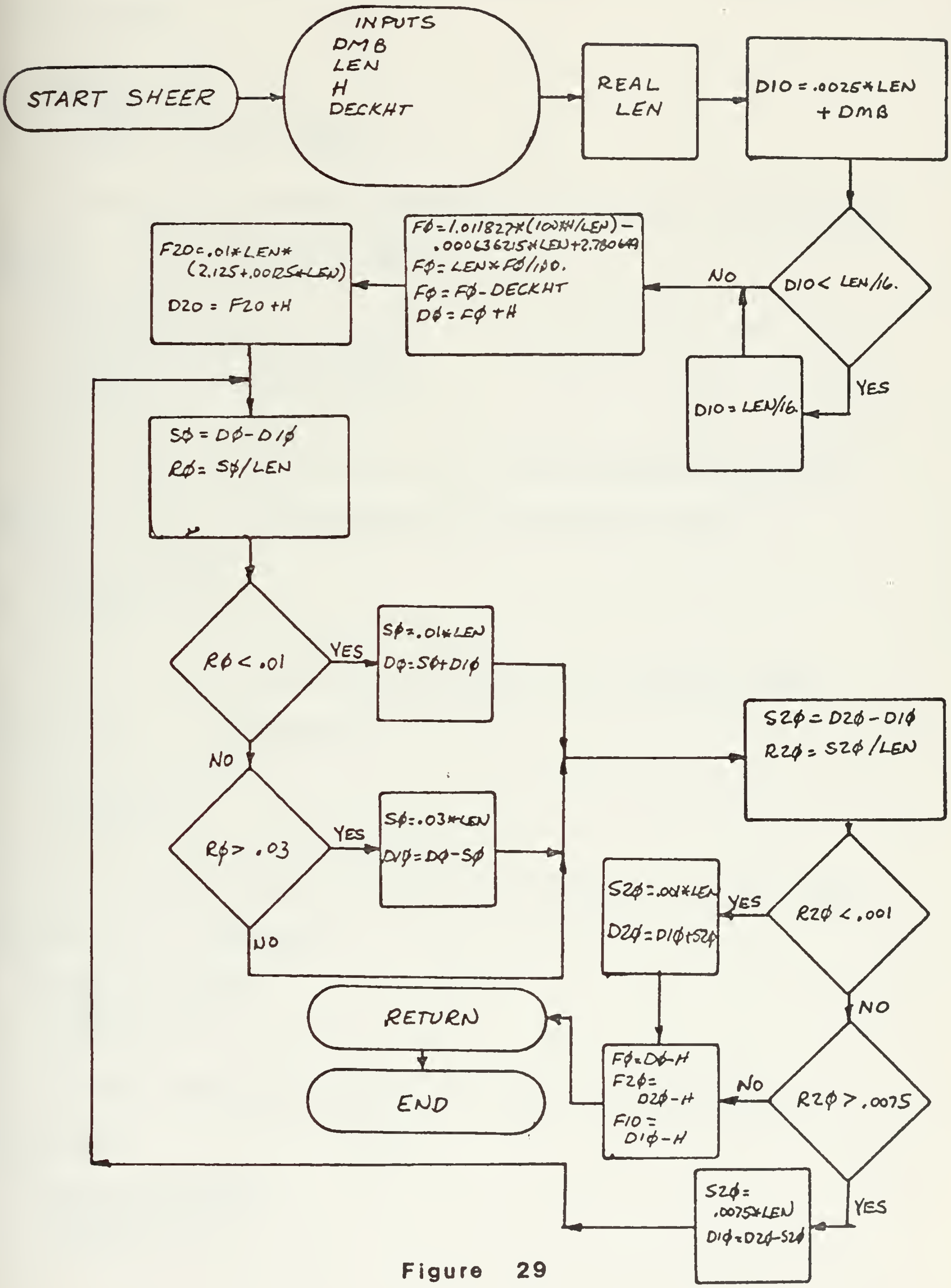


Figure 29

```
F20=.01*LEN*(2.125+.00125*LEN)
D20=F20+H
```

Finally the minimum depth at the after perpendicular is selected.

```
7 S0=D0-D10
  R0=S0/LEN
  IF(R0.LT..01) GOTO 1
  IF(R0.GT..03) GOTO 2
```

The sheer fraction forward is calculated and checked against the acceptable limits.

```
6 S20=D20-D10
  R20=S20/LEN
  IF(R20.LT..001) GOTO 3
  IF(R20.GT..0075) GOTO 4
  GOTO 5
```

The sheer fraction at the after perpendicular is calculated and checked against acceptable limits.

```
1 S0=.01*LEN
  D0=S0+D10
  GOTO 6
```

If the freeboard at the bow is too low the depth at the bow is increased.

```
2 S0=.03*LEN
  D10=D0-S0
  GOTO 6
```

If the freeboard at the bow is excessive, the depth amidships is increased.

```
3 S20=.001*LEN
  D20=D10+S20
  GOTO 5
```

If the freeboard aft is too low the depth aft is increased.

```
4 S20=.0075*LEN
  D10=D20-S20
  GOTO 7
```

If the freeboard aft is excessive the depth amidships is increased and the sheer fraction at the bow is rechecked.

```
5 F0=D0-H
  F20=D20-H
  F10=D10-H
  RETURN
  END
```

Values of both freeboard and depth are returned for use in subroutine volume.

3.11.4 Output List for Subroutine SHEER

F0...............SCDA	D0................SCDA
F10..............SCDA	D10...............SCDA
F20..............SCDA	D20...............SCDA

3.11.5 Nomenclature List

D0	depth at forward perpendicular, ft
D10	depth at amidships, ft
D20	depth at after perpendicular, ft
DECKHT	height of raised deck, ft
DMB	machinery box depth, ft
F0	freeboard at bow, ft
F10	freeboard amidships, ft
F20	freeboard at stern, ft
H	draft, ft
LEN	length between perpendiculars, ft
R0	(D0-D10)/LEN
R20	(D20-D10)/LEN
S0	D0-D10
S20	D20-D10

3.12 Subroutine WEIGHT

3.12.1 Introduction

Subroutine VOLUME balanced the required and available volumes in the hull. This subroutine estimates weights so that a balance can be made between full load weight and displacement.

Several of the weights required have already been calculated or were given as input. Calculated weights include the fuel weight and lub oil weight. All communications and control, group 4, weights and all armament, group 7, weights are given as input. The weight groups noted refer to the NAVSHIPS Hull Group Weight Classification of 1965. The categories in this classification scheme are given in Appendix E. This is the classification system now used by the Coast Guard.

Also given as input are the weights of cargo, aircraft, ammunition and aircraft fuel. All other weights which are a part of the full load weight are estimated in subroutine WEIGHT. A flow chart for this routine is shown in Figure 30.

There are few patrol cutters of recent vintage which can be used for collecting weight data. Three have been used throughout this model. These are the 378' WHEC, the 210' WMEC, and the 150' WPB. Wherever possible additional data has been shown. Light ship weight data was taken from the weight breakdown sheets prepared for each design. Load weights were taken from

WEIGHT SUBROUTINE
FLOW CHART

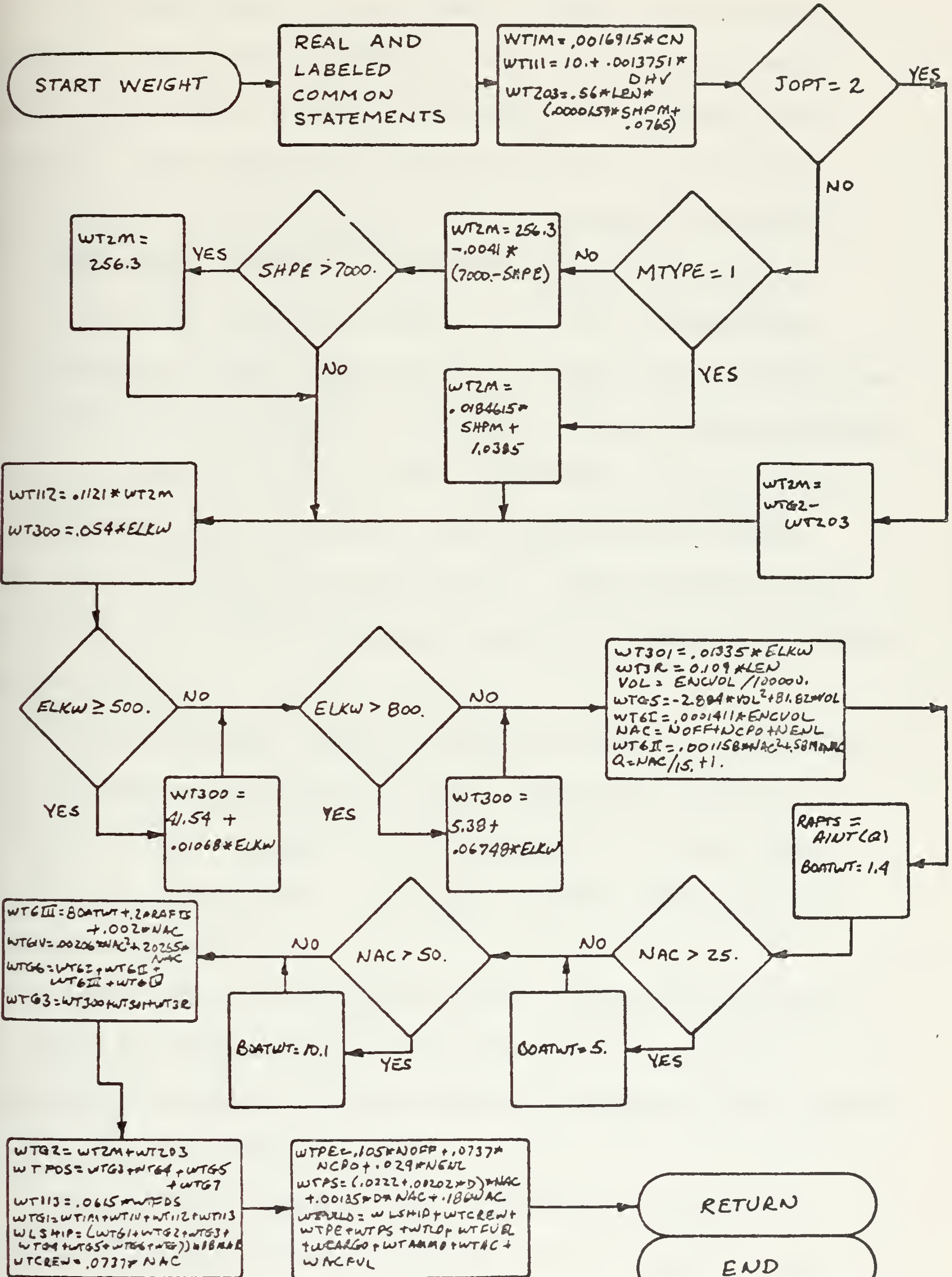


Figure 30

either load weight calculations or from inclining experiment data.

The first hull weight group is the hull structure, group 1. In order to estimate this weight group more accurately, three of the sub-groups are estimated separately. The remainder of the sub-groups are lumped together as a single group. In the program this group is referred to as WT1M. The three groups subtracted are group 111, superstructure; group 112, foundations for propulsion plant machinery; and group 113, foundations for auxiliaries and other equipment. These are identified in the program as WT111, WT112, and WT113, respectively.

Figure 31 is a plot of WT1M versus cubic number. The correlation here is very good. Also included on the figure is the estimating line used in the Navy's destroyer model, DD07.

Superstructure weight, WT111, is shown in Figure 32. plotted against deckhouse volume. The line labeled no uptakes is the one used in the program. The line used in DD07 is also shown. This line assumes that the deckhouse is aluminum.

The weight of propulsion plant foundations, WT112, is shown in Figure 33 plotted against the weight of propulsion machinery minus shafting and propellers. Again, a line used in DD07 is shown.

WT113, other foundations, is shown in Figure 34 versus the total weight of groups 3, 4, 5, and 7. The

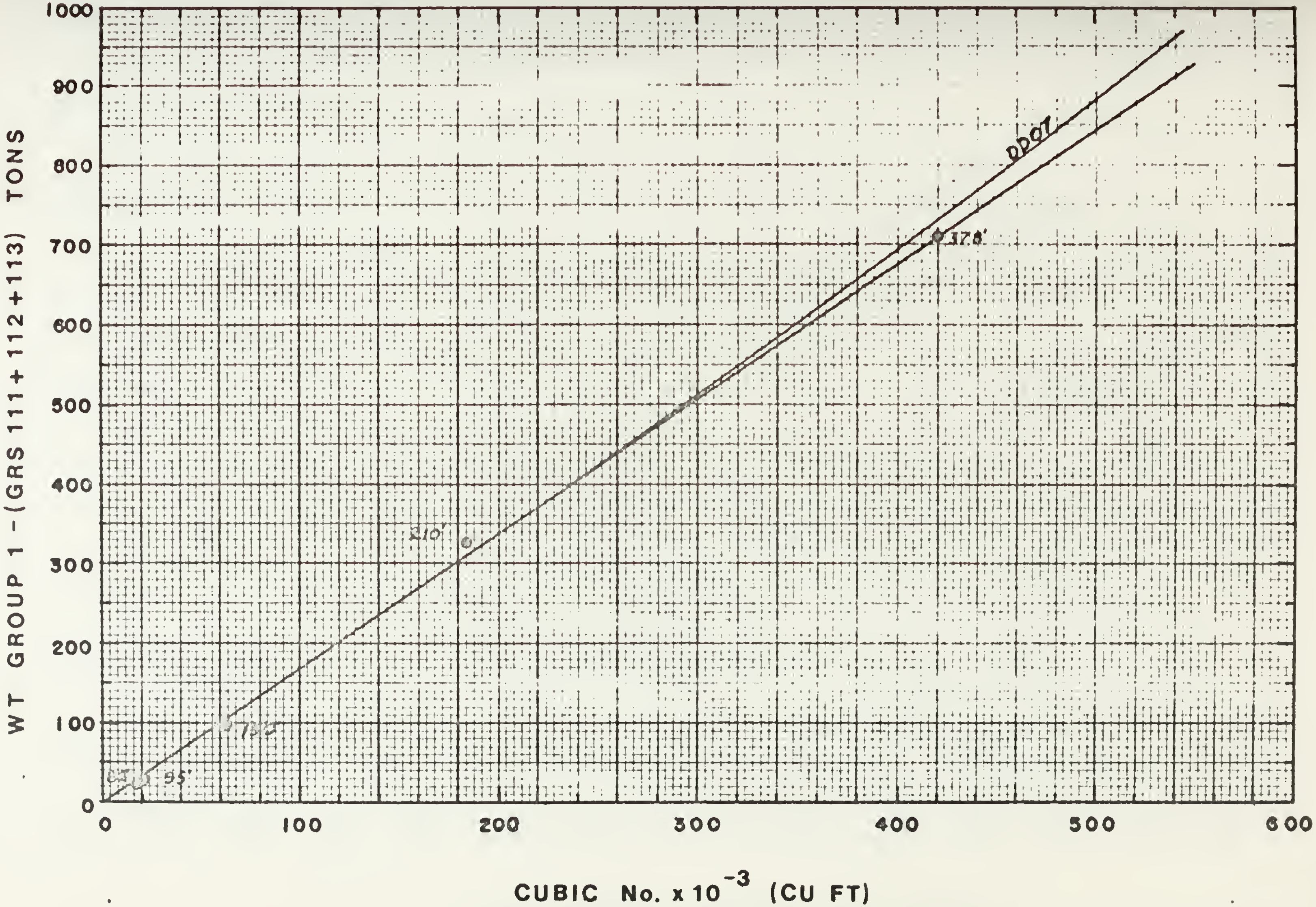
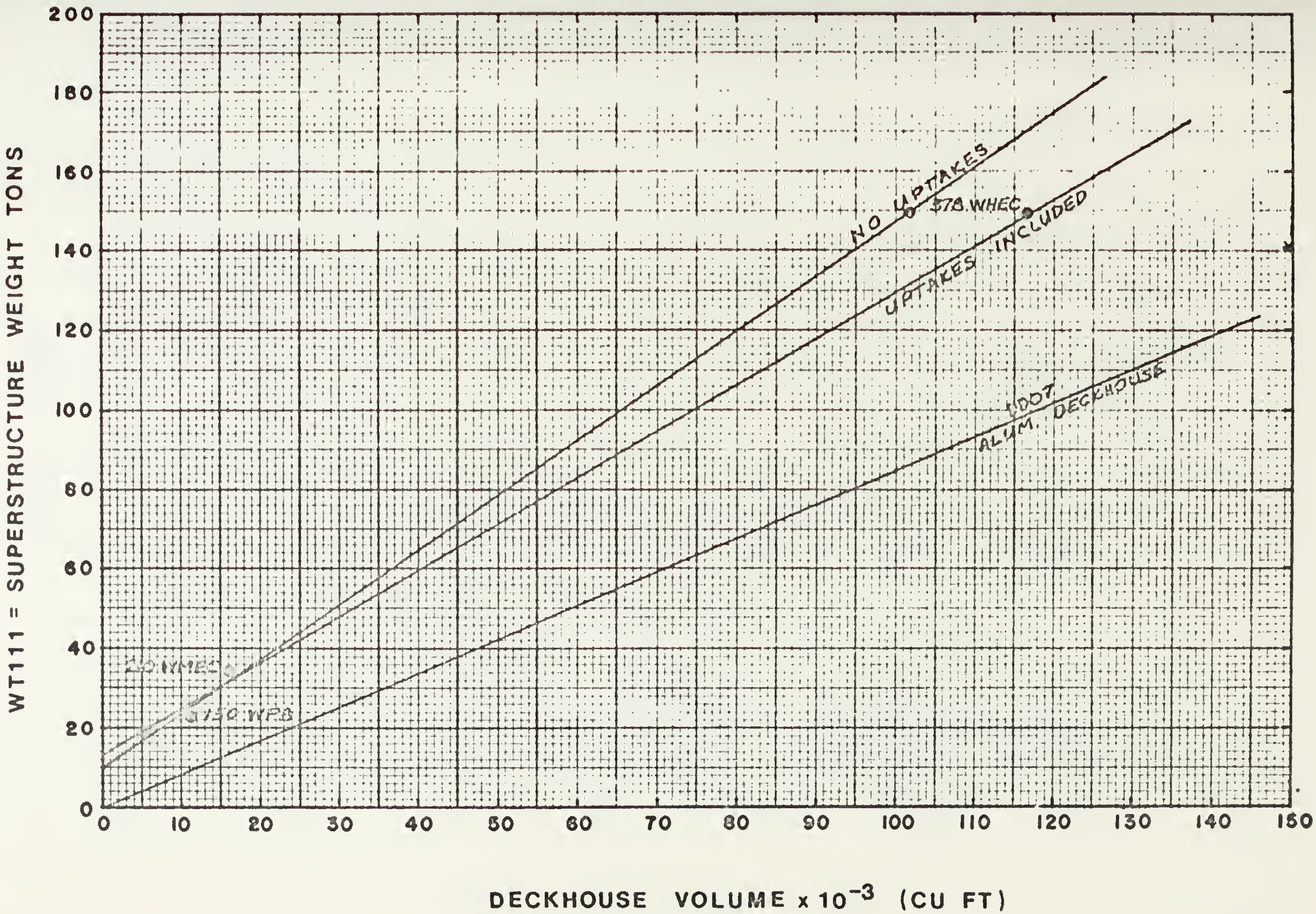
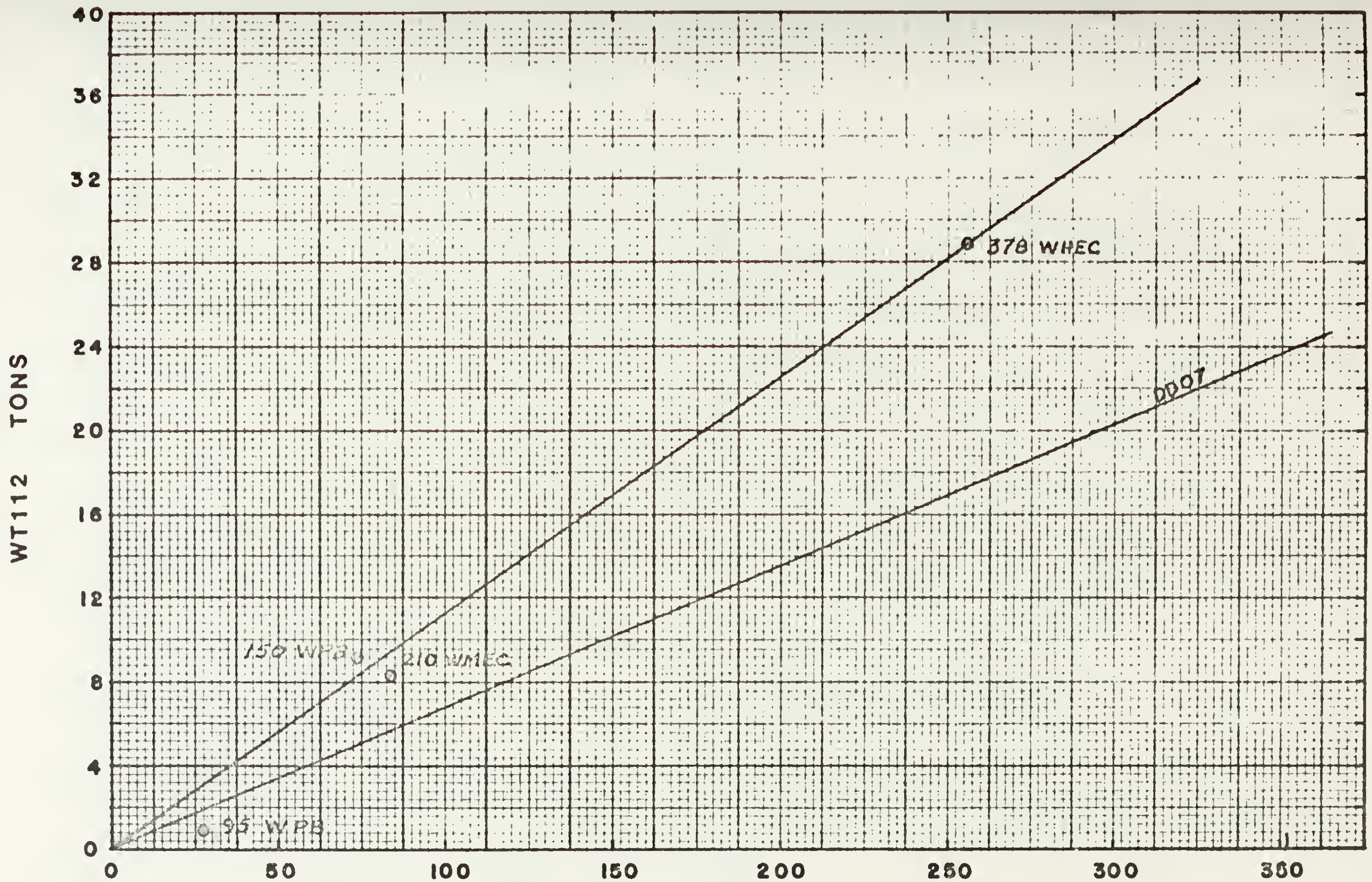

WT GROUP 1 - (GRS 111 + 112 + 113) TONS
CUBIC No. x 10^-3 (CU FT)
0
100
200
300
400
500
600
700
800
900
1000
DDG7
378'
210'
95'

Figure 31



WT111 = SUPERSTRUCTURE WEIGHT TONS
DECKHOUSE VOLUME x 10^{-3} (CU FT)
0
20
40
60
80
100
120
140
160
180
200
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
NO UPTAKES
378 WHEC
UPTAKES INCLUDED
ALUM. DECKHOUSE

Figure 32



WT2M = WTG2 - WT203 TONS

Figure 33

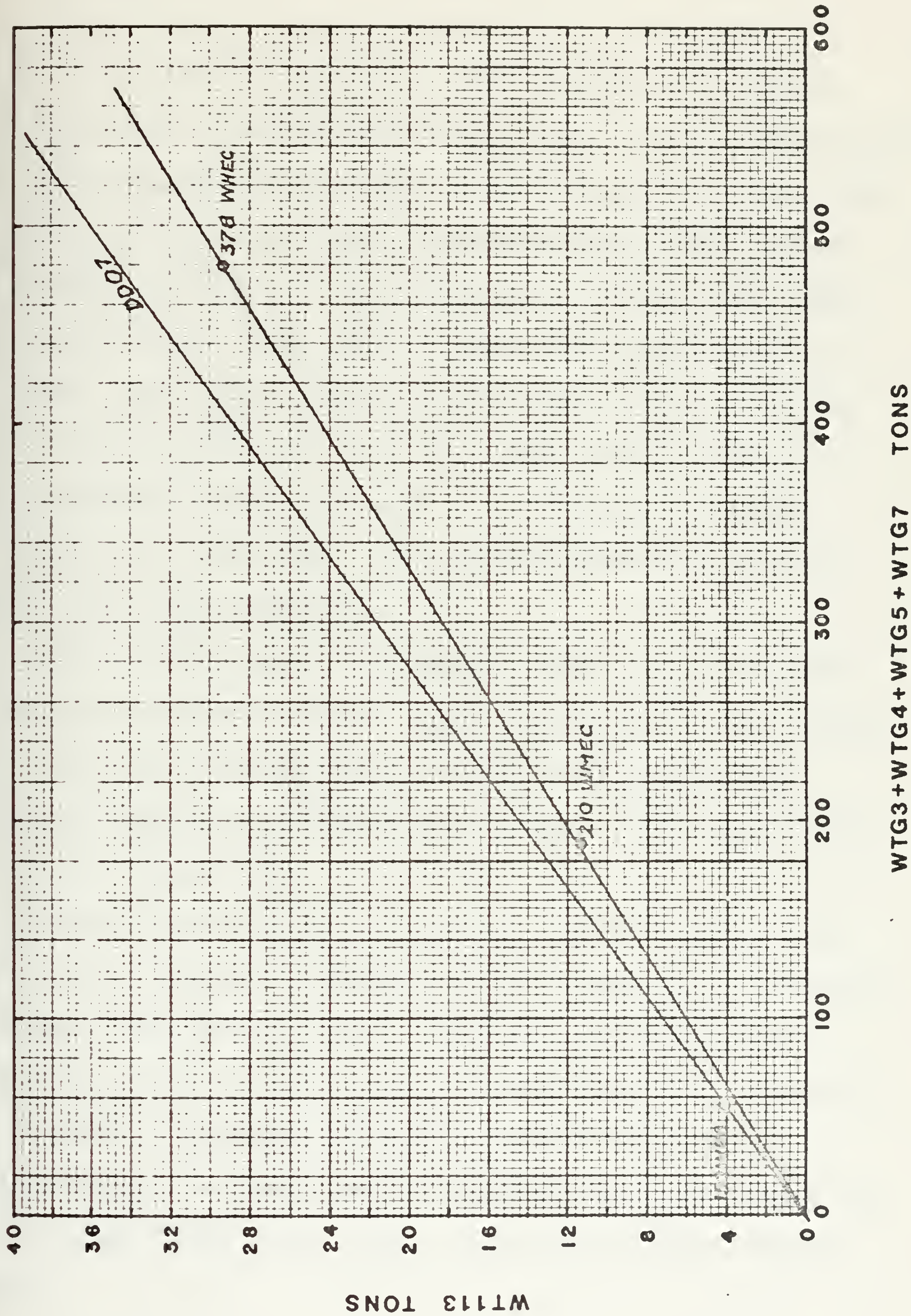

DDG?
378 WHEC
210 WHEC
0
4
8
12
16
20
24
28
32
36
40
WT113 TONS
0
100
200
300
400
500
600
WTG3+WTG4+WTG5+WTG7 TONS

Figure 34

correlation here appears reasonable; however, there is a difference between the data and the DD07 estimate.

Propulsion machinery is classified under group 2. In this program, an estimate of the weight of sub-group 203 (shafting, bearings, and propellers) was made separately. The remaining sub-groups were estimated as one group, WT2M. A plot of WT2M versus shaft horsepower for diesel plants is shown in Figure 35. Here more data is available from non patrol types. The DD07 estimate for diesel plants is poor. For CODOG plants it is assumed that the diesel plant will be 7000 horsepower or under and that only the endurance power will cause a difference in weight from that of a 378' WHEC. A lower endurance power will reduce the weight somewhat.

Shafting and propeller weight, WT203, is calculated as weight per foot of shaft length versus shaft horsepower. Twin shafts are assumed with a total shaft length 0.56 times the length of the ship. A plot of this relationship is shown in Figure 36.

Group 3 includes the electrical plant weights. The Coast Guard intends to install electric plants of relatively larger capacity in future ships so a simple linear estimation using current designs is unrealistic. Instead, the weights of a number of diesel generating sets of various capacities have been plotted as shown in Figure 37. The varying RPM of these plants resulted in three weight ranges.

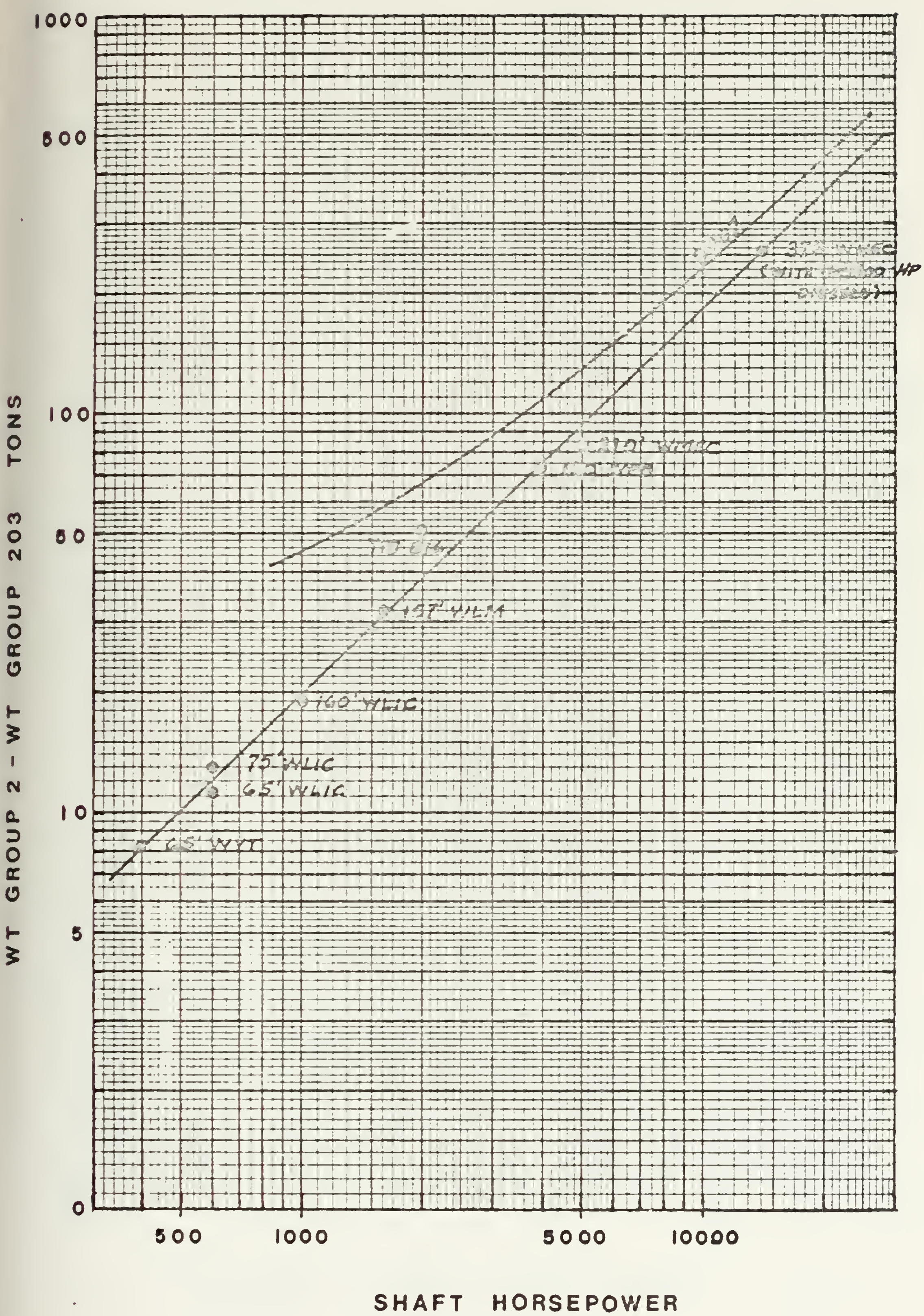

1000
500
100
50
10
5
0
WT GROUP 2 - WT GROUP 203 TONS
157' WLM
160' WLIC
75' WLIC
65' WLIC
65' WYT
500
1000
5000
10000
SHAFT HORSEPOWER

Figure 35

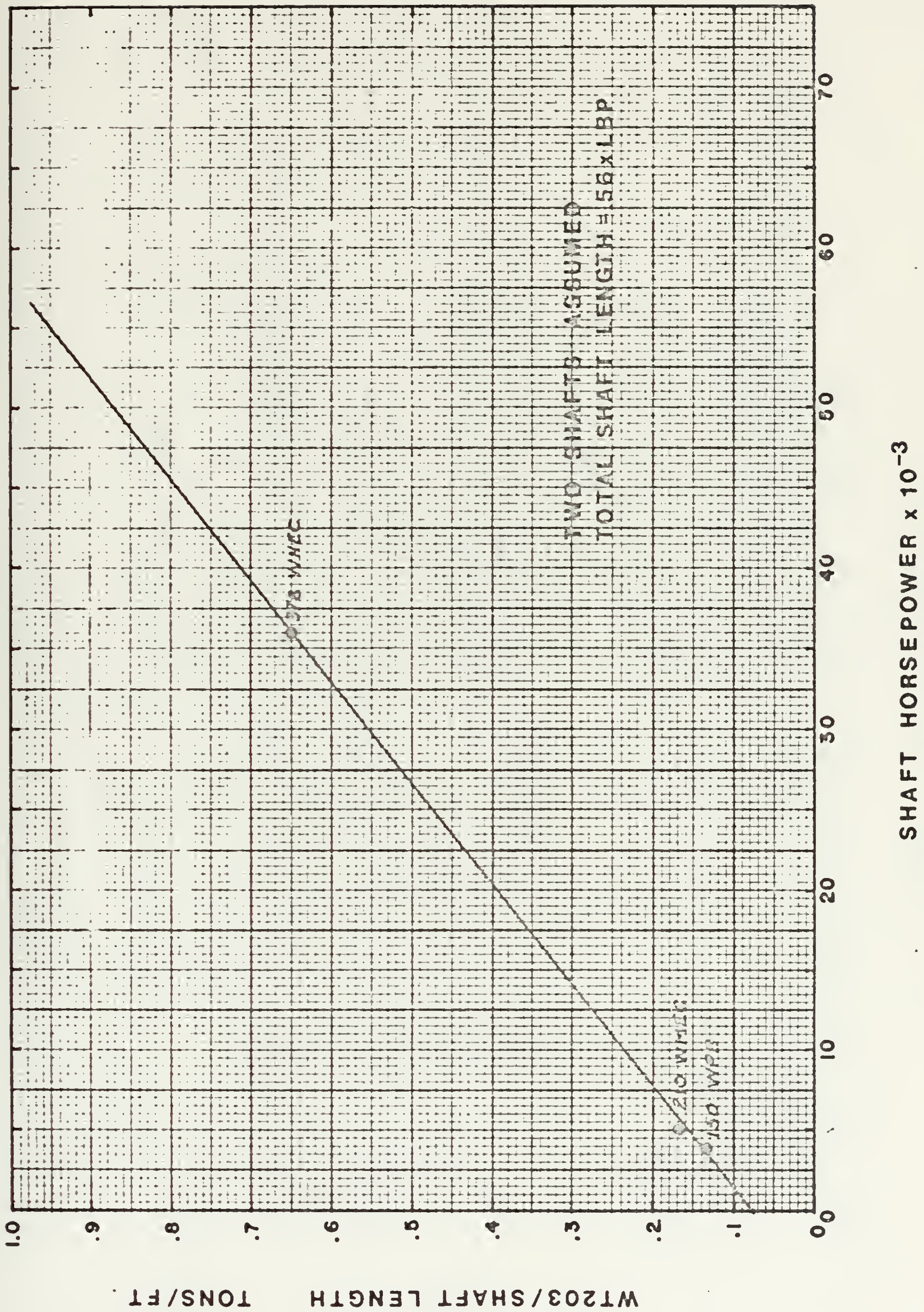

WT203/SHAFT LENGTH TONS/FT
SHAFT HORSEPOWER x 10^{-3}
0 10 20 30 40 50 60 70
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0
TWO SHAFTS ASSUMED
TOTAL SHAFT LENGTH = .56 x LBP
378 WHEC
210 WMEC

Figure 36

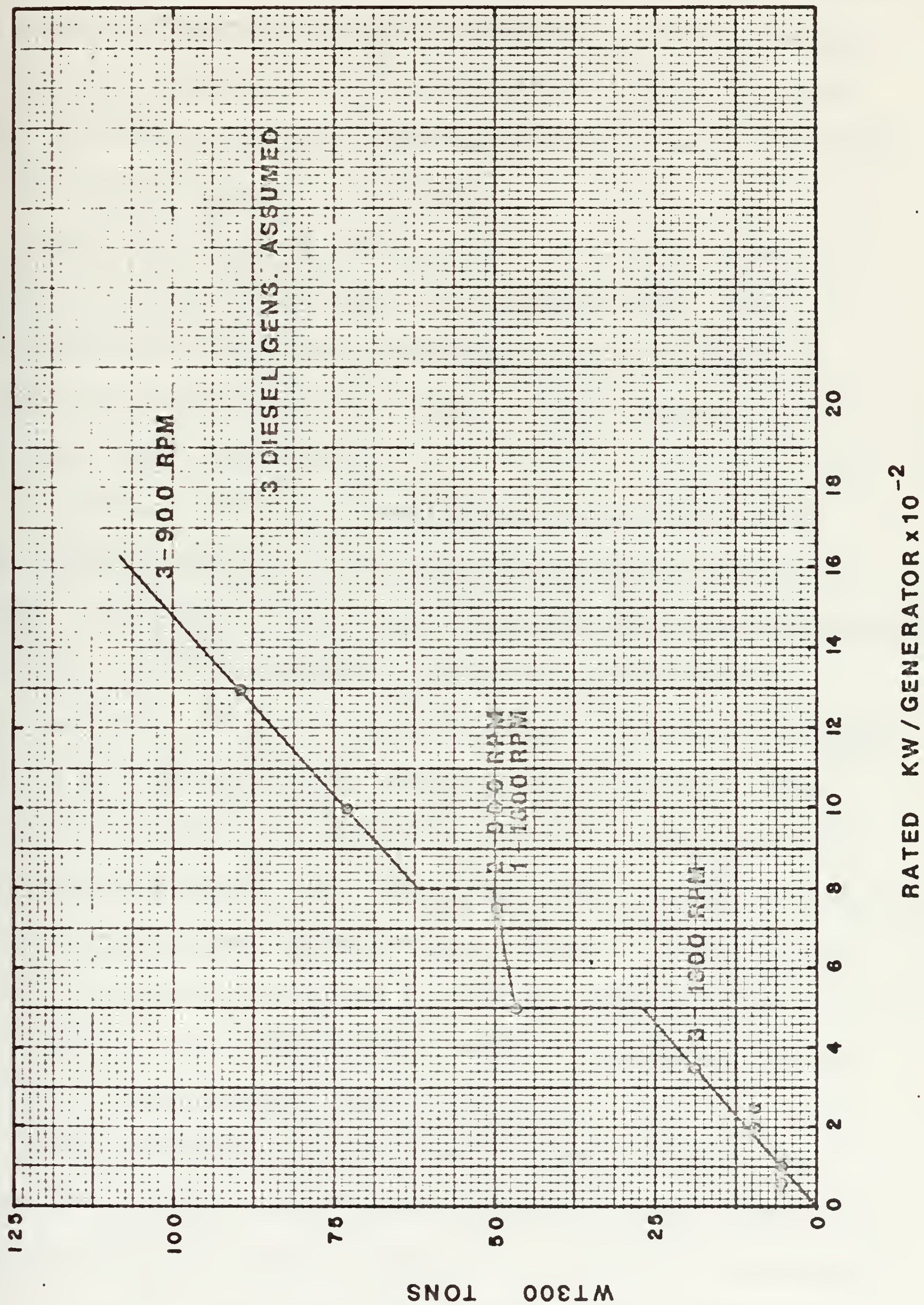

3-900 RPM
3 DIESEL GENS. ASSUMED
2-900 RPM
1-1800 RPM
3-1800 RPM
WT300 TONS
0
25
50
75
100
125
0
2
4
6
8
10
12
14
16
18
20
RATED KW/GENERATOR x10^-2

Figure 37

The weight of the generating sets is only a part of the group 3 weight. The weight of switchboards, WT301, is shown in Figure 38 as is the remaining group 3 weight, WT3R. The correlation for these weight groups is quite bad. Fortunately, these weights make up a small percentage of the total weight of the ship.

Since group 4 weights are given as input, group 5 weights, auxiliary systems, is estimated next. The destroyer model uses the estimating relation shown in Figure 39. The three Coast Guard vessels agree very well with this relationship .

Group 6, outfit and furnishings is the last light ship group estimated since group 7 weights are given as input. Group 6 is broken into four sub-groups for estimating purposes. The first, WT6I, includes groups 600, 602, 603, and 605. These are hull fittings, rigging and canvas, ladders and gratings, and painting, respectively. The second group, WT6II, includes groups 604, nonstructural bulkheads and doors; 606, deck covering; 607, hull insulation; and 608, storerooms, stowages and lockers. Group three, WT6III, includes only group 601, boats, boat stowage and handling. The final group, WT6IV, includes all the remaining sub-groups of weight group 6.

WT6I plotted against enclosed volume is shown in Figure 40. WT6II and WT6IV are plotted against number of accommodations as shown in Figure 41. WT6III is estimated in three parts. The first is a boat weight, the second a

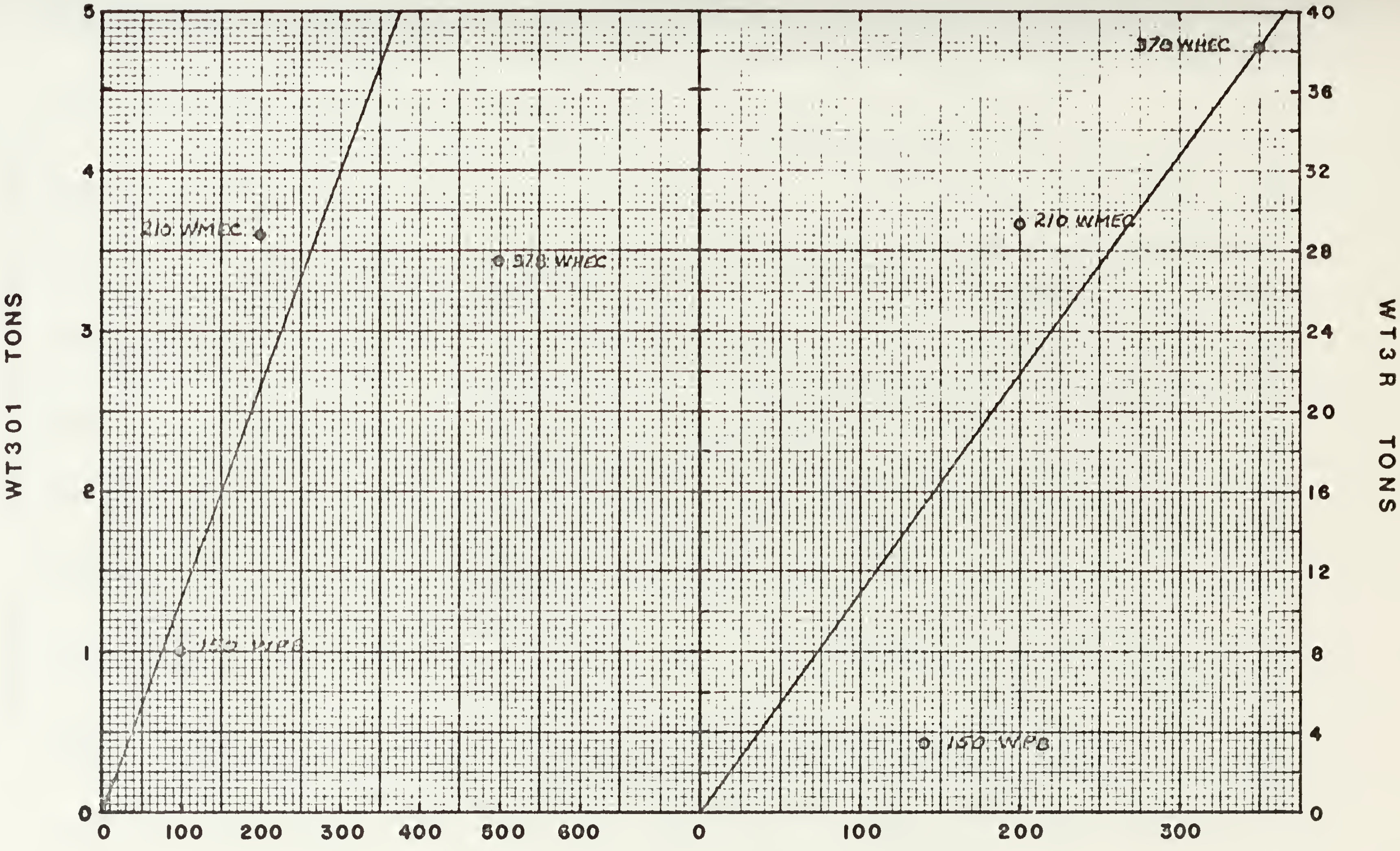
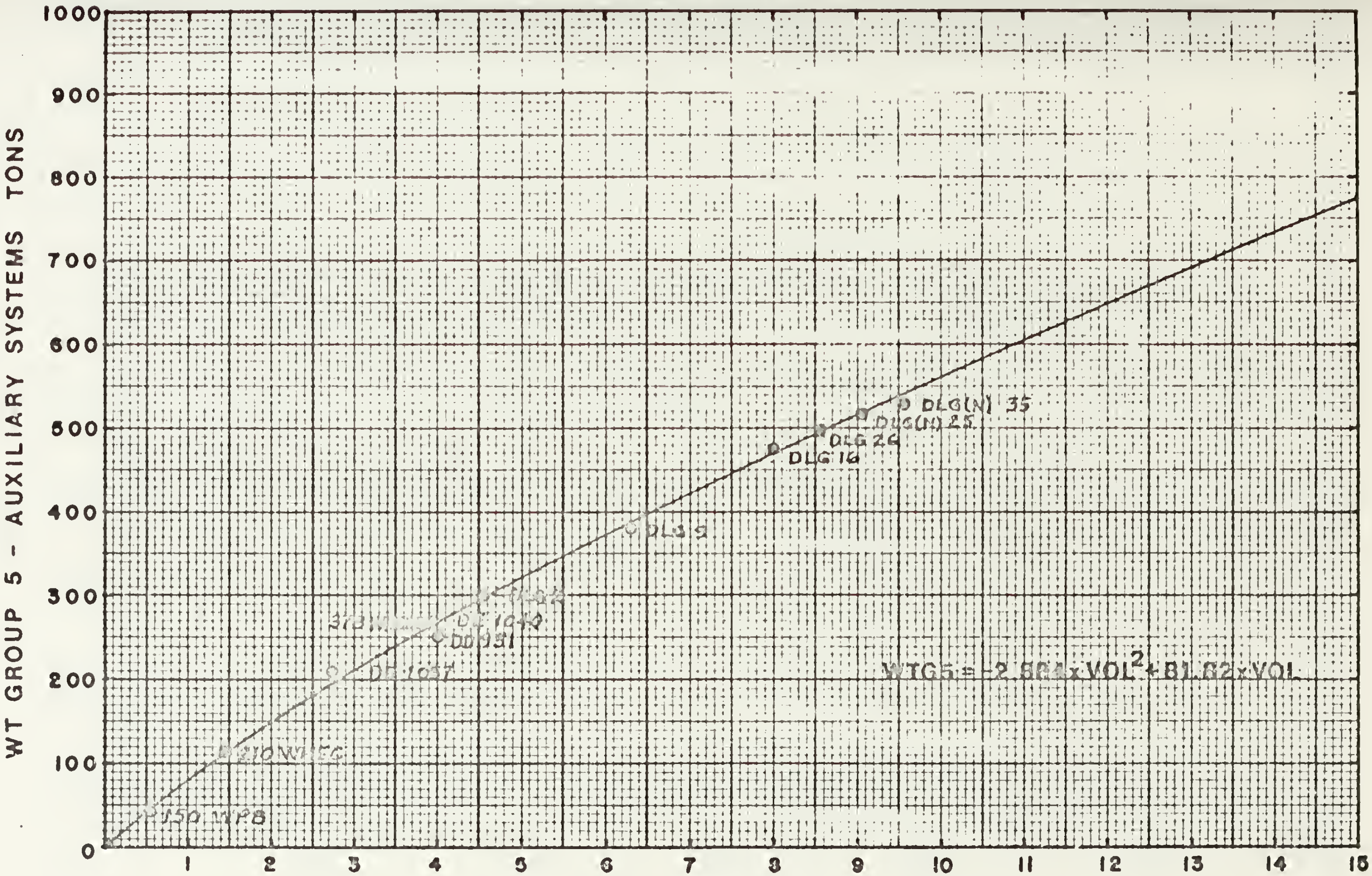

WT301 TONS
WT3R TONS
0
1
2
3
4
5
0
4
8
12
16
20
24
28
32
36
40
210 WMEC
378 WHEC
150 WPB
210 WMEC
378 WHEC
150 WPB
0
100
200
300
400
500
600
0
100
200
300
KW/GEN
LBP FT

Figure 38

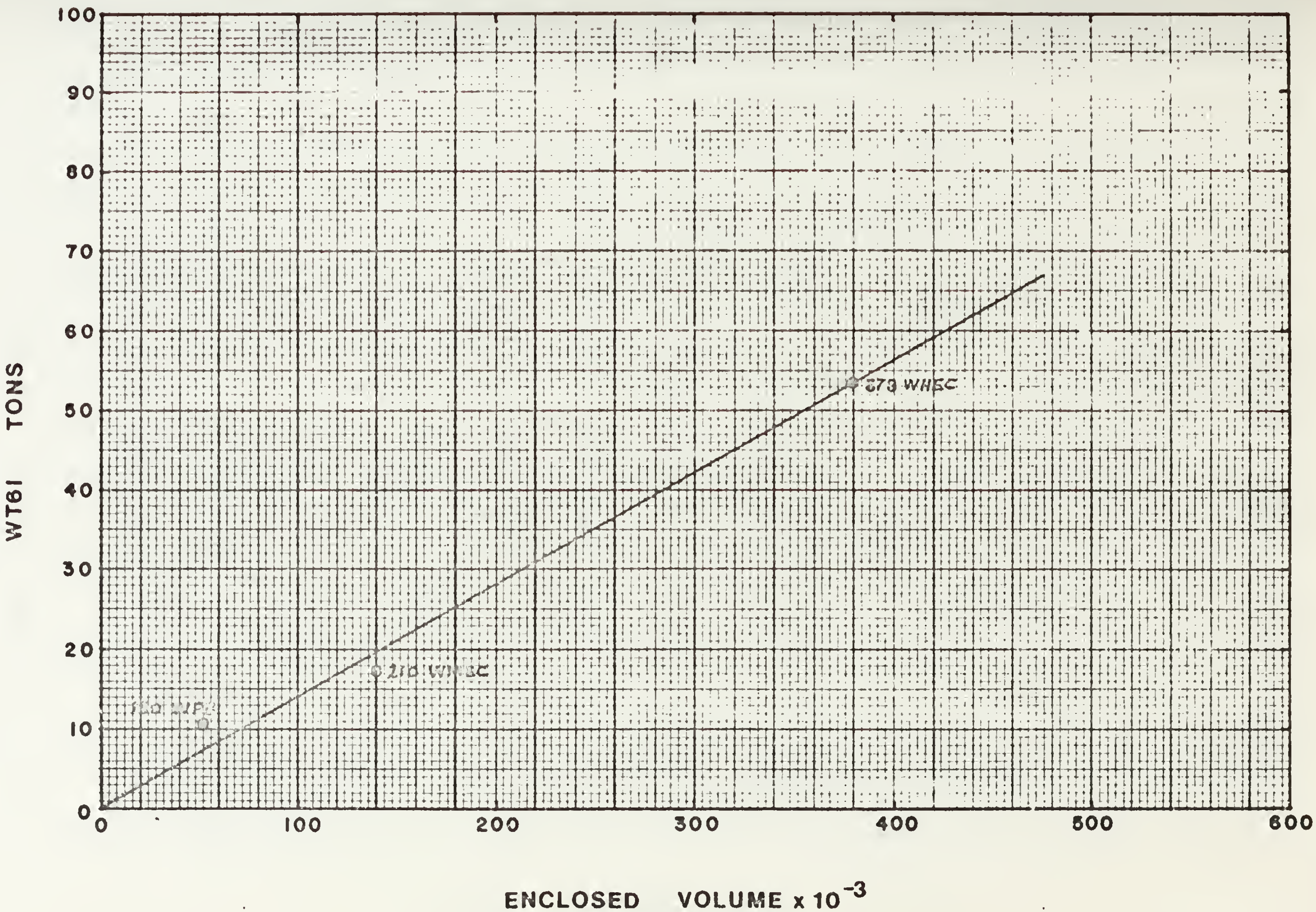
Figure 39



VOL

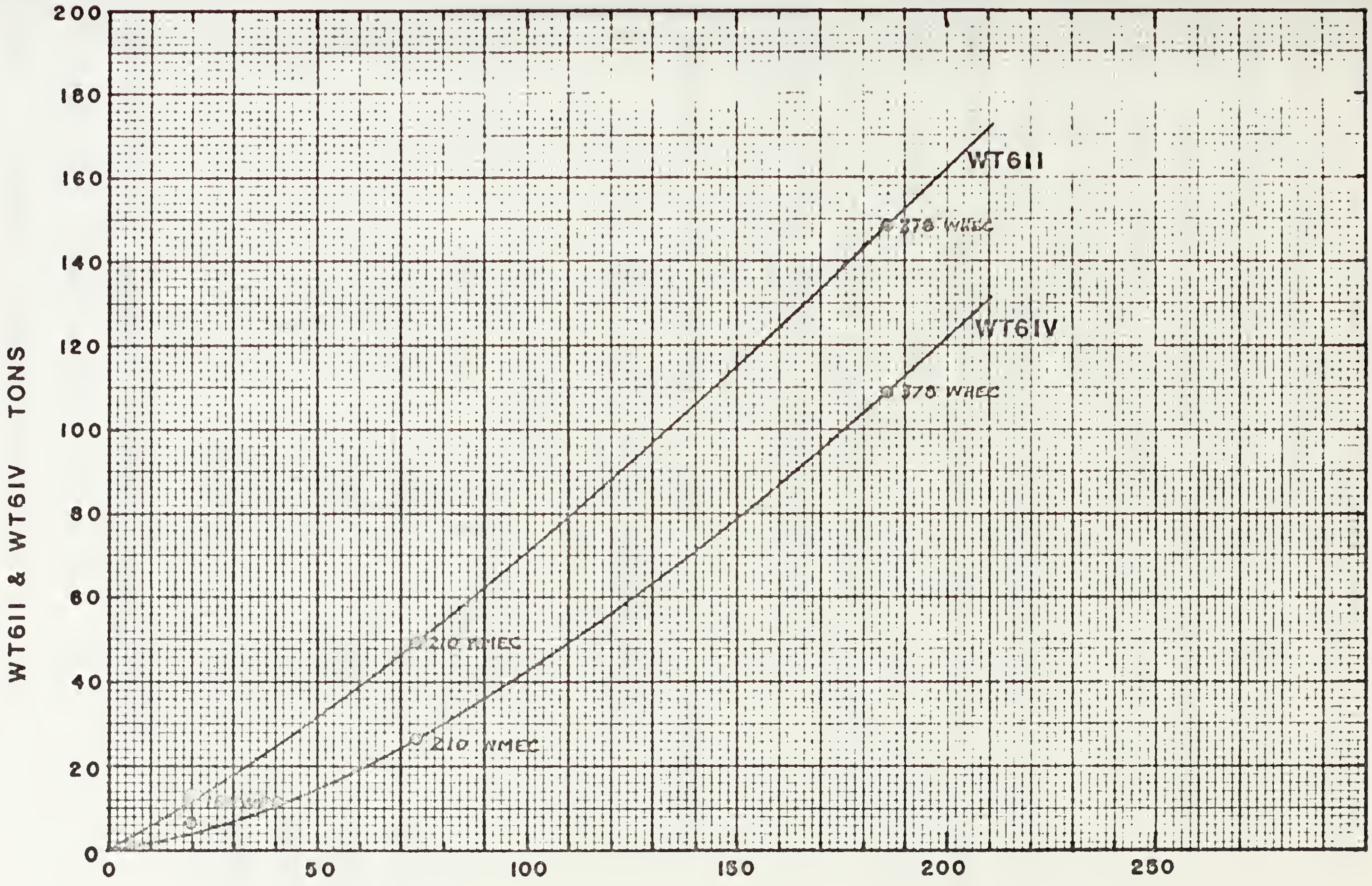
TOTAL ENCLOSED VOLUME x 10^{-5}

FOR CG VESSELS = $\triangle$x35+1.1xBxLBPx(DAVG−T)xCWP+VOL_{dh}(no uptakes)



100
90
80
70
60
50
40
30
20
10
0
WT61 TONS
0
100
200
300
400
500
600
373 WHEC
210 WHEC
ENCLOSED VOLUME x 10^{-3}

Figure 40



No. of ACCOMMODATIONS

Figure 41

liferaft weight and the third a lifejacket weight.

All of the lightship weights are summed and then multiplied by a design and builders margin. The design and builders margin is an input.

Crew weight is taken to be 0.0737 tons per man or 165 pounds per man. Personal effects are calculated as 0.105 tons per man for officers, .0737 for chiefs and .029 for enlisted men.

The weight of personnel stores includes provisions, general stores, and potable water. The weight of provisions is based on Table 3. The data in this table was reduced to a formula for which only the endurance days of dry provisions need be given. This formula is:

$(.0222 + .00202 \times D) \times NAC$

where D is the endurance days for dry provisions

NAC is the number of accommodations

Table 3

days endurance	pounds/person			
	dry prov.	frozen	chilled	total
30	97.0	36.8	51.8	185.6
45	145.5	55.2	52.8	253.5
60	194.0	73.6	53.8	321.4
90	291.0	110.4	55.8	457.2

The weight of general stores is taken to be

$.00135 \times D \times NAC$

and that of potable water to be

$.186 \times NAC$ or 50 gallons/man

The full load weight can then be calculated by adding the load weights to the light ship weight.

3.12.2 Input List for Subroutine WEIGHT

CN...............LC(BB)	SHPE..............LC(CC)
D................LC(AA)	SHPM..............LC(CC)
DBMAR............LC(WW)	WACFUL............LC(LL)
DHV..............LC(BB)	WCARGO............LC(LL)
ELKW.............LC(DD)	WTAC..............LC(LL)
ENCVOL...........LC(BB)	WTAMMO............LC(LL)
JOPT.............LC(CC)	WTFUEL............LC(LL)
LEN..............LC(BB)	WTG2*.............LC(WW)
MTYPE............LC(CC)	WTG4..............LC(WW)
NCPO.............LC(AA)	WTG7..............LC(WW)
NENL.............LC(AA)	WTLO..............LC(LL)
NOFF.............LC(AA)	

*only if JOPT = 2

3.12.3 Statement Descriptions

A detailed description of each statement will not be given for this routine wince the flow of the program follows the description given in the introduction and the relationships are those plotted.

One area that will be discussed is WT6III. Here the number of 15 man liferafts required is first calculated.

```
Q=NAC/15.+1.
RAFTS=AINT(Q)
```

where AINT is a function which drops the decimal fraction

from its argument. Boat weight is assumed to be 1.4 tons up to 25 men, 5 tons between 25 and 50 men and 10.1 tons above 50 men. This weight includes launching equipment. Lifejacket weight is taken to be .002 tons per man.

3.12.4 Output List for Subroutine WEIGHT

WFULLD	LC(WW)	WT6II	LC(VV)
WLSHIP	LC(WW)	WT6III	LC(VV)
WT111	LC(VV)	WT6IV	LC(VV)
WT112	LC(VV)	WTCREW	LC(LL)
WT113	LC(VV)	WTG1	LC(WW)
WT1M	LC(VV)	WTG2*	LC(WW)
WT203	LC(VV)	WTG3	LC(WW)
WT2M	LC(VV)	WTG5	LC(WW)
WT300	LC(VV)	WTG6	LC(WW)
WT301	LC(VV)	WTPE	LC(LL)
WT3R	LC(VV)	WTPS	LC(LL)
WT6I	LC(VV)		

* only if JOPT = 1

3.12.5 Nomenclature List

The definition of all variables is the same as given in the MAIN program nomenclature except for the following:

BOATWT	boat weight, tons
D	same as ENDDAY in MAIN
NAC	number of accommodations
Q	dummy argument

RAFTS	number of liferafts
RE	same as RGEND in MAIN
SFCH	same as SFCHHP in MAIN
SFCM	same as SFCMHP in MAIN
VE	same as VEND in MAIN
VOL	enclosed volume x 10^{-5}
WT111	weight of group 111, tons
WT112	weight of group 112, tons
WT113	weight of group 113, tons
WT1M	weight of remainder of group 1, tons
WT203	weight of group 203, tons
WT2M	weight of remainder of group 2, tons
WT300	weight of group 300, tons
WT301	weight of group 301, tons
WT3R	weight of remainder of group 3, tons
WT6I	see text
WT6II	see text
WT6III	see text
WT6IV	see text
WTFDS	sum of weight groups 3, 4, 5, and 7

3.13 Subroutine VCG

3.13.1 Introduction

The vertical center of gravity of the ship is estimated in this routine. The designer has some latitude with regard to the location of the center of gravity; therefore, the value calculated by this routine should be viewed as a feasible rather tnan as the best value.

The effect that the vcg has on the design can be investigated by using different values of free surface correction. The free surface correction is added to the KG. Therefore, either a positive or a negative value can be used to represent a shift in the KG location.

In order to determine feasible locations for the various centers, data for the 378' WHEC, the 210' WMEC, and the 150' WPB was used. This data is shown in Tables 4 and 5. On these tables the vcgs of the various weight groups are shown. These centers are related to various hull depths by a factor K. The hull depth used is given in the right hand column of these tables. An average coefficient, K, was chosen and is given in the column labeled Coef. K.

The variables to which the vcgs are referred were chosen arbitrarily by observing which gave the most consistent set of coefficients among the three ships.

Some of the weight groups shown in the tables are really input items. These weight groups are included to assist the designer in choosing realistic values to

VERTICAL CENTERS OF GRAVITY

Weight		378' WHEC	210' WMEC	150' WPB	Coef. K	times
WT1M	vcg	15.78	14.72	9.55		
	K	.553	.547	.584	.55	DAVG
WT111	vcg	37.1	35.3	23.6		
	K	1.4	1.26	1.47	1.4	D10
WT112	vcg	5.73	4.4	2.5		
	K	.216	.157	.156	.2	D10
WT113	vcg	21.05	16.6	15.1		Center groups
	K	.794	.593	.944	.87	3+4+5+7
WT2M	vcg	15.14	10.40	8.50		
	K	.571	.533	.531	.54	D10MN
WT203	vcg	4.02	6.0	2.6		
	K	.152	.214	.163	.16	D10
WT300	vcg	20.35	14.7	19.0		
	K	.768	.525	1.19	.7	D10
WT301	vcg	21.3	11.8	21.0		
	K	.804	.421	1.31	.8	D10
WT3R	vcg	27.5	19.41	17.79		
	K	1.038	.693	1.11	1.0	D10
WTG5	vcg	19.43	16.68	13.5		
	K	.733	.596	.844	.71	D10
WT6I	vcg	20.66	20.43	15.09		
	K	.78	.73	.943	.75	D10
WT6II	vcg	26.48	21.93	19.23		
	K	1.0	.783	1.2	1.0	D10
WT6III	vcg	41.75	33.9	25.9		
	K	1.575	1.738	1.62	1.6	D10MN
WT6IV	vcg	24.88	20.97	13.46		
	K	.939	.749	.841	.84	D10
WTG4	vcg	31.56	35.0	22.6		
	K	1.191	1.25	1.41	1.3	D10
WTG7	vcg	35.26	24.45	21.3		
	K	1.33	.873	1.33	1.3	D10

Table 4

VERTICAL CENTERS OF GRAVITY

Weight		378' WHEC	210' WMEC	150' WPB	Coef. K	times
Crew & Personal Effects	vcg	26.26	20.43	15.0		
	K	.964	1.048	.938	.97	D10MN
Provisions	vcg	15.0	15.0	11.0		
	K	.55	.536	.688	.55	D10
General Stores	vcg	24.05	16.16	11.0		
	K	.883	.829	.688	.85	D10MN
Ammo	vcg	15.99	8.4	19.0		
	K	.587	.431	1.19	.5	D10MN
Potable Water	vcg	7.06	8.5	4.2		
	K	.26	.30	.263	.26	D10
L.O.	vcg	3.58	2.5	12.0		
	K	.131	.128	.75	.13	D10MN
Fuel	vcg	7.67	8.17	6.6		
	K	.281	.292	.412	.3	D10
Aircraft	vcg	39.01				
	K	1.43			1.4	D10
A/C Fuel	vcg	9.56				
		.351			.351	D10
DAVG		28.54	26.91	16.36		
D10		27.25	28.0	16.0		
D10MN		27.25	19.5	16.0		

Table 5

VCG SUBROUTINE
FLOW CHART

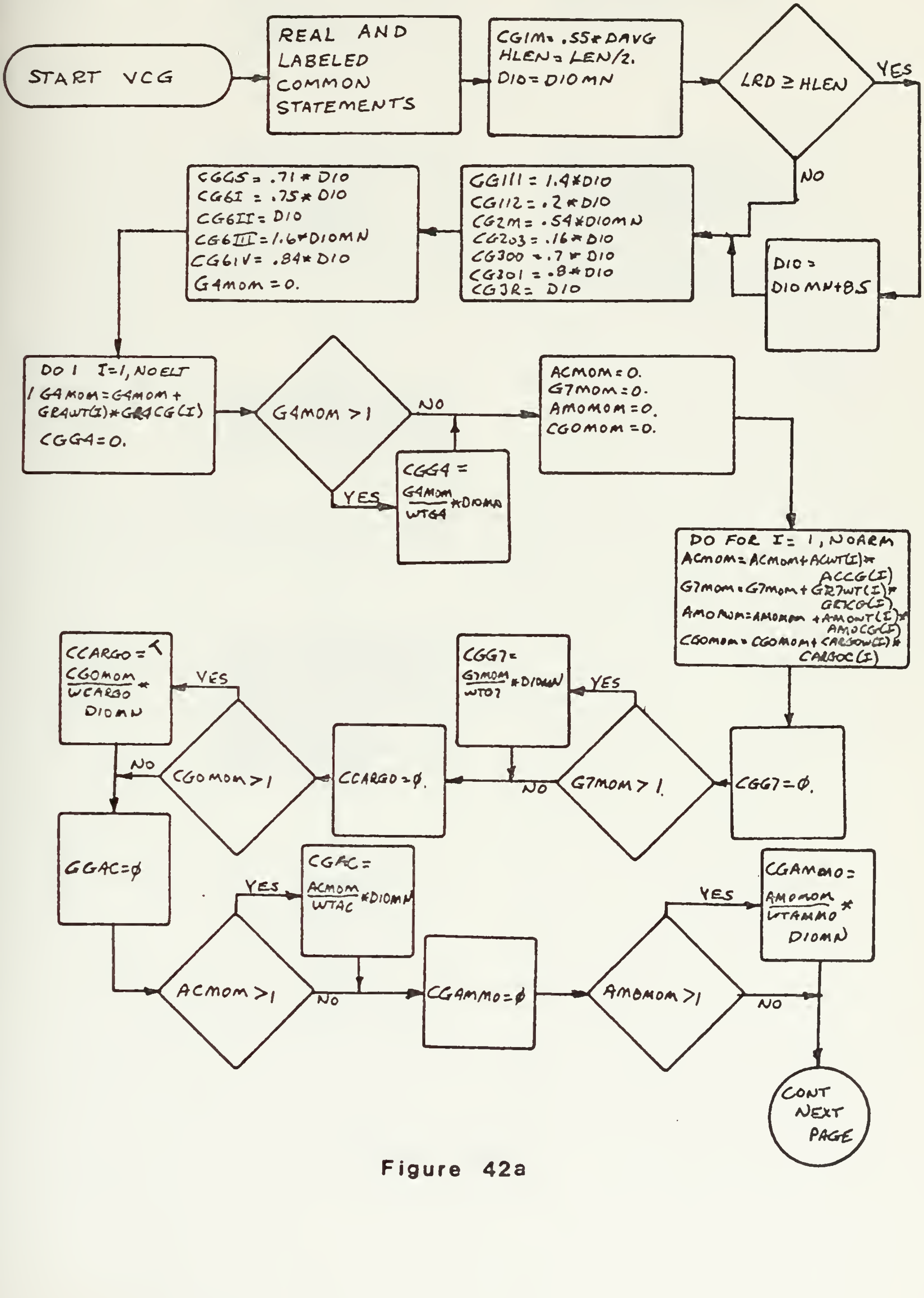


Figure 42a

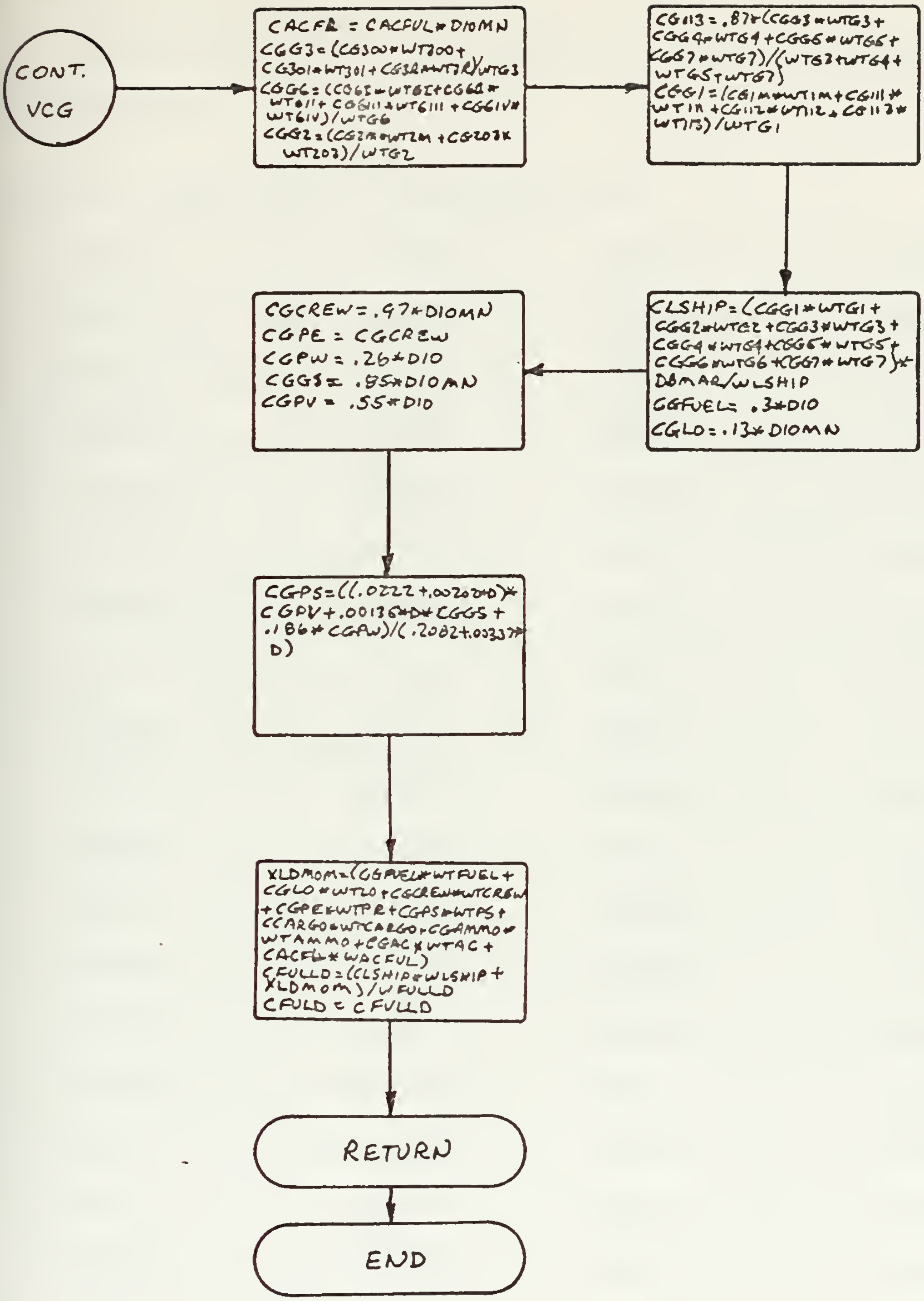

CONT. VCG
CACFR = CACFUL*DIOMN
CGG3=(CG300*WT300+
CG301*WT301+CG3R*WT3R)/WTG3
CGG6=(CG6I*WT6I+CG6II*
WT6II+CG6III*WT6III+CG6IV*
WT6IV)/WTG6
CGG2=(CG2M*WT2M+CG203*
WT203)/WTG2
CG113=.87*(CGG3*WTG3+
CGG4*WTG4+CGG5*WTG5+
CGG7*WTG7)/(WTG3+WTG4+
WTG5+WTG7)
CGG1=(CG1M*WT1M+CG111*
WT1M+CG112*WT112+CG113*
WT113)/WTG1
CLSHIP=(CGG1*WTG1+
CGG2*WTG2+CGG3*WTG3+
CGG4*WTG4+CGG5*WTG5+
CGG6*WTG6+CGG7*WTG7)*
DBMAR/WLSHIP
CGFUEL= .3*D10
CGLO=.13*DIOMN
CGCREW=.97*DIOMN
CGPE = CGCREW
CGPW=.26*D10
CGGS= .85*DIOMN
CGPV = .55*D10
CGPS=((.0222+.00202*D)*
CGPV+.00136*D*CGGS+
.186*CGPW)/(.2082+.00337*
D)
XLDMOM=(CGFUEL*WTFUEL+
CGLO*WTLO+CGCREW*WTCREW
+CGPE*WTPR+CGPS*WTPS+
CCARGO*WTCARGO+CGAMMO*
WTAMMO+CGAC*WTAC+
CACFL*WACFUL)
CFULLD=(CLSHIP*WLSHIP+
XLDMOM)/WFULLD
CFULD = CFULLD
RETURN
END

Figure 42b

input.

A flow chart for this routine is shown in Figures 42a and 42b.

3.13.2 Input List for Subroutine VCG

ACCG............LC(EE)	WT113............LC(VV)
ACWT............LC(EE)	WT1M.............LC(VV)
AMOCG...........LC(EE)	WT203............LC(VV)
AMOWT...........LC(EE)	WT2M.............LC(VV)
CACFUL..........LC(HH)	WT300............LC(VV)
CARGOC..........LC(EE)	WT301............LC(VV)
CARGOW..........LC(EE)	WT3R.............LC(VV)
D...............LC(AA)	WT6I.............LC(VV)
D10MN...........LC(II)	WT6II............LC(VV)
DAVG............LC(BB)	WT6III...........LC(VV)
DBMAR...........LC(WW)	WT6IV............LC(VV)
GR4CG...........LC(EE)	WTAMMO...........LC(LL)
GR4WT...........LC(EE)	WTCREW...........LC(LL)
GR7CG...........LC(EE)	WTFUEL...........LC(LL)
GR7WT...........LC(EE)	WTG1.............LC(WW)
LEN.............LC(BB)	WTG2.............LC(WW)
LRD.............LC(JJ)	WTG3.............LC(WW)
NOARM...........LC(FF)	WTG4.............LC(WW)
NOELT...........LC(FF)	WTG5.............LC(WW)
WACFUL..........LC(LL)	WTG6.............LC(WW)
WCARGO..........LC(LL)	WTG7.............LC(WW)
WFULLD..........LC(WW)	WTLO.............LC(LL)

WLSHIP.............LC(WW)	WTPE...........LC(LL)
WT111..............LC(VV)	WTPS...........LC(LL)
WT112..............LC(VV)	

3.13.3 Statement Descriptions

Detailed statement descriptions will not be given for this routine. In general the statements consist of vcg estimates using the relationships mentioned in the introduction or of calculations to combine weight groups by summing the vertical moments of individual groups and dividing by the total weight.

Note that D10 is different from D10MN only if the length of raised deck is greater than one half the ship length. It must also be remembered that input moment arms are given as fractions of the main deck depth at amidships and not as a distance in feet.

3.13.4 Output List for Subroutine VCG

CCARGO...........LC(OO)	CGG3..........LC(OO)
CFULD..............SCDA	CGG4..........LC(OO)
CFULLD...........LC(OO)	CGG5..........LC(OO)
CGAC.............LC(HH)	CGG6..........LC(OO)
CGAMMO...........LC(HH)	CGG7..........LC(OO)
CGCREW...........LC(HH)	CGLO..........LC(HH)
CGFUEL...........LC(HH)	CGPE..........LC(HH)
CGG1.............LC(OO)	CGPS..........LC(HH)
CGG2.............LC(OO)	CLSHIP........LC(OO)

3.13.5 Nomenclature List

ACMOM	total vertical aircraft moment, tons
AMOMOM	total vertical ammunition moment, tons
CACFL	vertical center aircraft fuel, ft
CFULD	same as CFULLD
CFULLD	vertical center of ship at full load, ft
CG111	vertical center of group 111, ft
CG112	vertical center of group 112, ft
CG113	vertical center of group 113, ft
CG1M	vertical center of group 1M, ft
CG203	vertical center of group 203, ft
CG2M	vertical center of group 2M, ft
CG300	vertical center of group 300, ft
CG301	vertical center of group 301, ft
CG3R	vertical center of group 3R, ft
CG6I	vertical center of group 6I, ft
CG6II	vertical center of group 6II, ft
CG6III	vertical center of group 6III, ft
CG6IV	vertical center of group 6IV, ft
CGG1	vertical center of group 1, ft
CGG2	vertical center of group 2, ft
CGG3	vertical center of group 3, ft
CGG4	vertical center of group 4, ft
CGG5	vertical center of group 5, ft
CGG6	vertical center of group 6, ft
CGG7	vertical center of group 7, ft
CGGS	vertical center of general stores, ft

CGOMOM	vertical moment of cargo, tons
CGPV	vertical center of provisions, ft
CGPW	vertical center of potable water, ft
CLSHIP	vertical center of light ship, ft
CPO	same as NCPO in MAIN
D	same as ENDDAY in MAIN
D0	depth at F.P., ft
D10	depth amidships to main or raised deck, ft
D10MN	depth amidships to main deck, ft
D20	depth at A.P., ft
ENL	same as NENL in MAIN
G4MOM	total group 4 moment, tons
G7MOM	total group 7 moment, tons
HLEN	half the length of the ship, ft
I	index
OFF	same as NOFF in MAIN
WT1M	weight group 1M, tons
WT111	weight group 111, tons
WT112	weight group 112, tons
WT113	weight group 113, tons
WT203	weight group 203, tons
WT2M	weight group 2M, tons
WT300	weight group 300, tons
WT301	weight group 301, tons
WT3R	weight group 3R, tons
WT6I	weight group 6I, tons
WT6II	weight group 6II, tons

WT6III	weight group 6III, tons
WT6IV	weight group 6IV, tons
XLDMOM	total load moment, ton-ft

3.14 Subroutine COST

3.14.1 Introduction

This subroutine is based exclusively on the preliminary cost estimating procedure currently used by the Coast Guard. To use the procedure, the weight of each of the seven light ship weight groups must be known. Linear graphs for man hours and material cost are then entered with these values to determine the cost and labor required for each weight group.

Various relationships are also given for determining design costs, construction services cost and miscellaneous costs. Miscellaneous costs include initial outfit equipment such as lifejackets as well as retrofit costs, spare parts and administrative or resident inspector's office costs.

The curves used in the procedure were converted to formulas and the procedure was programmed as subroutine COST. A flow chart for this routine is given in Figure 43.

All of the material cost curves are based on 1959 prices. Indices are used to correct the prices to the year the ship will be built. These indices are based on Bureau of Labor Statistics data for the particular weight group.

The labor rate for all of the weight groups is assumed to be the same. The labor rate is inputed as an average dollars per hour for the year the ship will be built.

COST SUBROUTINE FLOW CHART

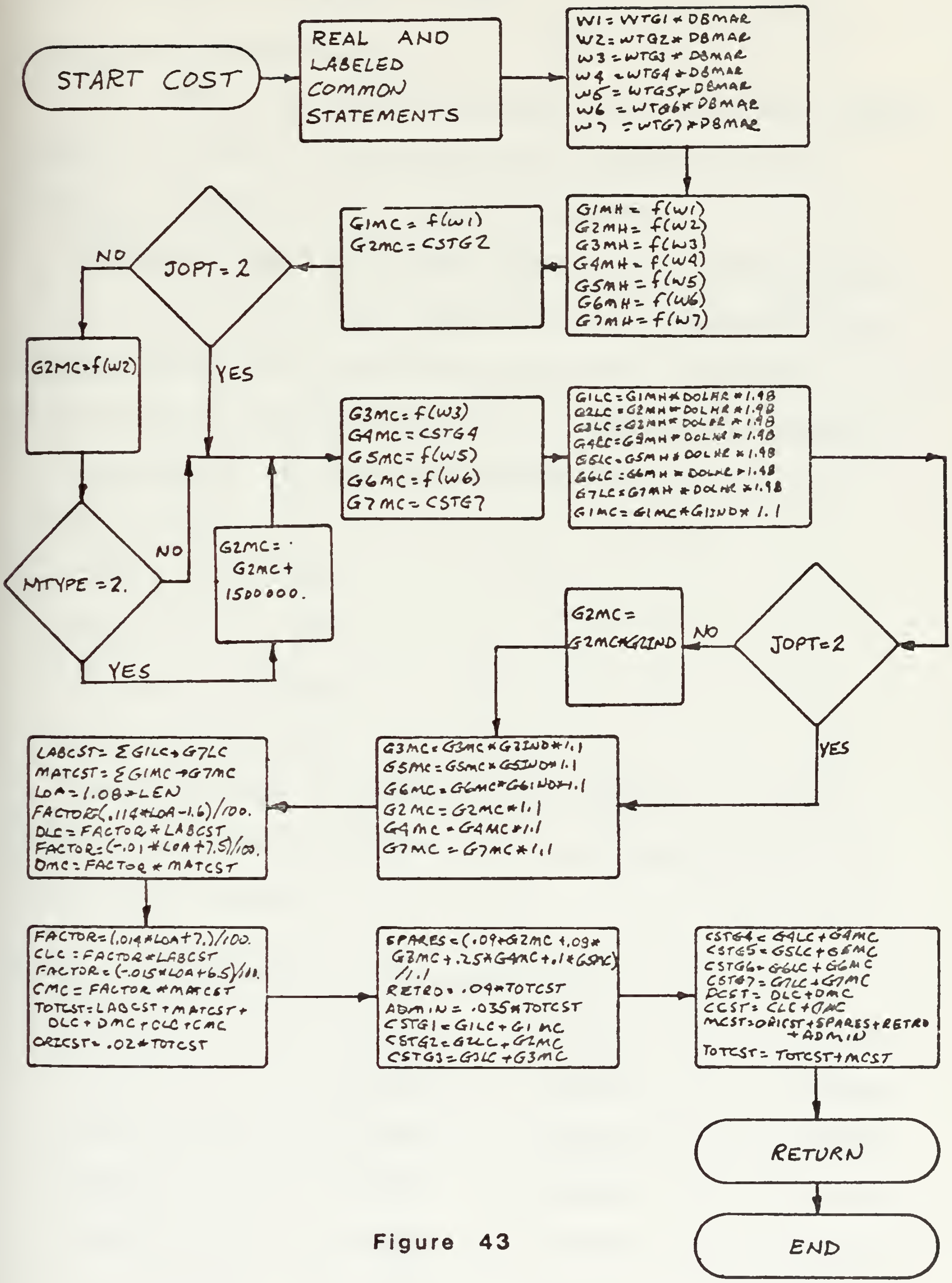


Figure 43

Material cost indices and labor rate data are shown in Figures 44 and 45. There is a large fluctuation in costs between shipyards so these numbers can only be viewed as average values.

In addition to the corrections for inflation, eighty percent is added to labor cost for overhead and ten percent is added to all costs for profit.

Initial outfit costs are assumed to be two percent of the total cost. Spare parts cost is the sum of the cost of spares for propulsion machinery, electrical machinery, electronics and outfit. The cost of spares as a percentage of the weight group material cost is given below:

Group 2 --- 9%

Group 3 --- 8%

Group 4 --- 25%

Group 5 --- 10%

Retrofit cost is assumed to be 4 percent of the total cost. Administrative socts are assumed to be 3.5 percent of the total.

3.14.2 Input List for Subroutine COST

CSTG2*..........LC(MM)	G1IND..........LC(NN)
CSTG4..........LC(MM)	G2IND..........LC(NN)
CSTG7..........LC(MM)	G3IND..........LC(NN)
DBMAR..........LC(WW)	G5IND..........LC(NN)
DOLHR..........LC(NN)	G6IND..........LC(NN)

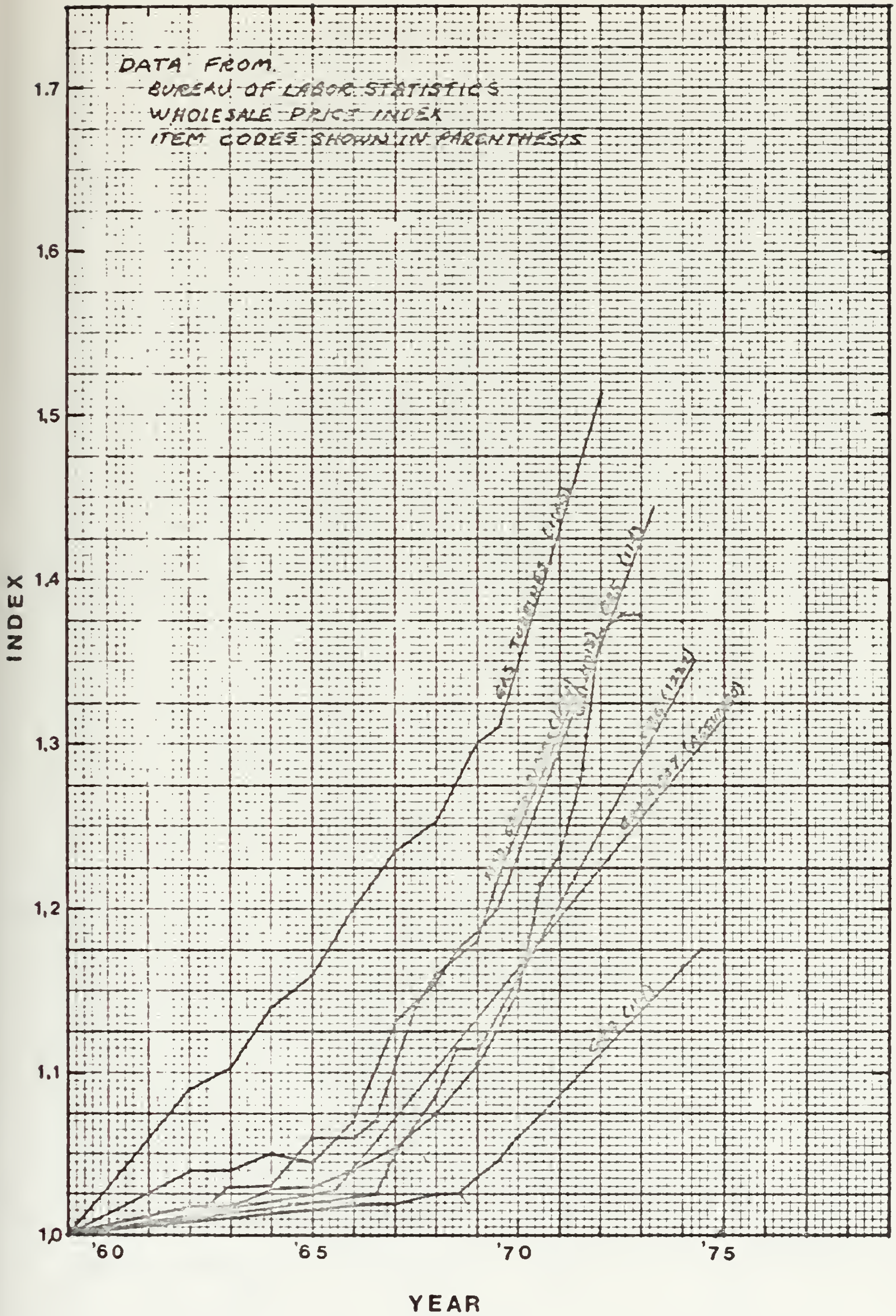

DATA FROM
BUREAU OF LABOR STATISTICS
WHOLESALE PRICE INDEX
ITEM CODES SHOWN IN PARENTHESIS
INDEX
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
'60
'65
'70
'75
YEAR

Figure 44

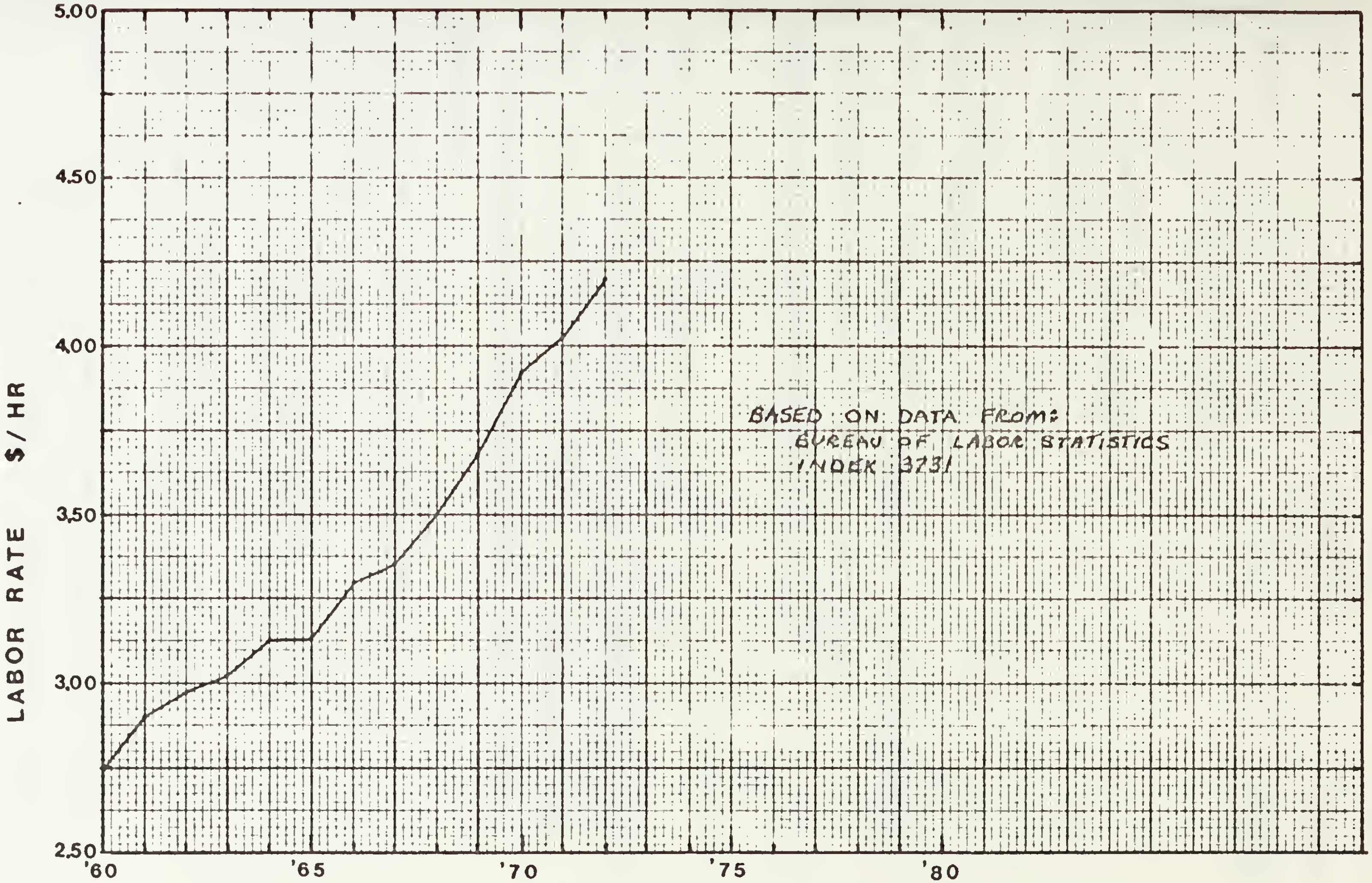

5.00
4.50
4.00
3.50
3.00
2.50
LABOR RATE $/HR
'60
'65
'70
'75
'80
YEAR
BASED ON DATA FROM:
BUREAU OF LABOR STATISTICS
INDEX 3731

Figure 45

JOPT.............LC(CC)	WTG3...........LC(WW)
LEN...............SCDA	WTG4...........LC(WW)
MTYPE............LC(CC)	WTG5...........LC(WW)
WTG1............LC(WW)	WTG6...........LC(WW)
WTG2............LC(WW)	WTG7...........LC(WW)

*only if JOPT = 2

3.14.3 Statement Descriptions

```
W1=WTG1*DBMAR
      .
      .
      .
W7=WTG7*DBMAR
```

The design and builders margin is evenly divided among the weight groups for costing purposes.

```
G1MH=10.**(ALOG10(W1)*.75217+2.97276)
      .
      .
      .
G7MH=10.**(ALOG10(W7)*.75217+2.97276)
```

These formulas represent the relationships between man-hours and the weight of individual weight groups. These relationships are assumed linear when plotted on log-log paper.

```
     G1MC=10.**(ALOG10(W1)*.954243+2.790484)
     G2MC=CSTG2
     IF(JOPT.EQ.2) GOTO 1
     G2MC=10.**(ALOG10(W2)*1.018885+3.634328)
     IF(MTYPE.EQ.2) G2MC=G2MC+1500000.
   1 G3MC=10.**(ALOG10(W3)*1.072551+3.667812)
     G4MC=CSTG4
     G5MC=10.**(ALOG10(W5)*.870906+3.974192)
     G6MC=10.**(ALOG10(W6)*1.068265+3.603833)
     G7MC=CSTG7
```

These formulas represent the material cost curves used by the Coast Guard. Some of these costs, CSTG2,

CSTG4 and CSTG7, are input. Group 2 cost is an input only if the machinery plant is specified. Otherwise, the machinery cost is calculated. The formula used represents the cost of diesel plants. An extra $1.5 million is added if a CODOG plant is to be installed.

```
     G1LC=G1MH*DOLHR*1.98
             .
             .
             .
     G7LC=G7MH*DOLHR*1.98
```

The labor cost by weight group is calculated here. The value, 1.98, represents an overhead factor of 1.8 times a profit factor of 1.1.

```
     G1MC=G1MC*G1IND*1.1
     IF(JOPT.EQ.2) GOTO 2
     G2MC=G2MC*G2IND
   2 G3MC=G3MC*G3IND*1.1
     G5MC=G5MC*G5IND*1.1
     G6MC=G6MC*G6IND*1.1
     G2MC=G2MC*1.1
     G4MC=G4MC*1.1
     G7MC=G7MC*1.1
```

In these formulas the material cost is corrected for inflation and a factor of 1.1 is included for profit. Note that the costs given as input are not corrected for inflation. Therefore, the cost of the equipment must be corrected for inflation before being inputed.

```
     LABCST=G1LC+G2LC+G3LC+G4LC+G5LC+G6LC+G7LC
     MATCST=G1MC+G2MC+G3MC+G4MC+G5MC+G6MC+G7MC
```

The total labor and material costs are calculated in these statements.

```
LOA=1.08*LEN
FACTOR=(.114*LOA-1.6)/100.
DLC=FACTOR*LABCST
FACTOR=(-.01*LOA+7.5)/100.
DMC=FACTOR*MATCST
```

These statements calculate the design labor, DLC, and design materials, DMC, costs for the first ship of a class from the beginning of the conceptual design stage. The two values of FACTOR are based on Coast Guard curves. Since the length overall is required in these curves, its value is estimated as eight percent greater than the length between perpendiculars.

```
FACTOR=(.014*LOA+7.)/100.
CLC=FACTOR*LABCST
FACTOR=(-.015*LOA+6.5)/100.
CMC=FACTOR*MATCST
```

The construction services labor and material costs are calculated here. Again the formulas for the two values of FACTOR are based on Coast Guard curves.

```
TOTCST=LABCST+MATCST+DLC+DMC+CLC+CMC
ORICST=.02*TOTCST
SPARES=(.09*G2MC+.08*G3MC+.25*G4MC+.1*G5MC)/1.1
RETRO=.04*TOTCST
ADMIN=.035*TOTCST
```

The four items that are included in the miscellaneous cost are calculated here. Since profit is included in the individual weight group material costs it is divided out when calculating the cost of spares.

```
CSTG1=G1LC+G1MC
      .
      .
      .
CSTG7=G7LC+G7MC
```

Total weight group costs are calculated here

```
DCST=DLC+DMC
CCST=CLC+CMC
MCST=ORICST+SPARES+RETRO+ADMIN
TOTCST=TOTCST+MCST
RETURN
END
```

Finally, the total design cost, construction services cost, miscellaneous cost and the total first ship cost are calculated.

3.14.4 Output List for Subroutine COST

CCST.............LC(MM)	CSTG6.............LC(MM)
CSTG1............LC(MM)	CSTG7.............LC(MM)
CSTG2*...........LC(MM)	DCST..............LC(MM)
CSTG3............LC(MM)	MCST..............LC(MM)
CSTG4............LC(MM)	TOTCST............LC(NN)
CSTG5............LC(MM)	

* only if JOPT = 1

3.14.5 Nomenclature List

The definition of all variables is the same as that given in the MAIN program nomenclature except for the following:

ADMIN	administrative costs, dollars
CLC	construction services labor cost, dollars
CMC	construction services material cost, dollars
DLC	design labor cost, dollars
DMC	design materials cost, dollars
FACTOR	see text
G1LC	weight group 1 labor cost, dollars

G2LC	weight group 2 labor cost, dollars
G3LC	weight group 3 labor cost, dollars
G4LC	weight group 4 labor cost, dollars
G5LC	weight group 5 labor cost, dollars
G6LC	weight group 6 labor cost, dollars
G7LC	weight group 7 labor cost, dollars
G1MC	weight group 1 material cost, dollars
G2MC	weight group 2 material cost, dollars
G3MC	weight group 3 material cost, dollars
G4MC	weight group 4 material cost, dollars
G5MC	weight group 5 material cost, dollars
G6MC	weight group 6 material cost, dollars
G7MC	weight group 7 material cost, dollars
G1MH	weight group 1 man-hours
G2MH	weight group 2 man-hours
G3MH	weight group 3 man-hours
G4MH	weight group 4 man-hours
G5MH	weight group 5 man-hours
G6MH	weight group 6 man-hours
G7MH	weight group 7 man-hours
LABCST	total construction labor cost, dollars
LOA	length overall, ft
MATCST	total construction material cost, dollars
ORICST	initial outfit cost, dollars
RE	same as RGEND in MAIN
RETRO	retrofit cost, dollars
SFCH	same as SFCHHP in MAIN

SFCM	same as SFCMHP in MAIN
SPARES	spare parts cost, dollars
VE	same as VEND in MAIN
W1	weight group 1 with margin, tons
W2	weight group 2 with margin, tons
W3	weight group 3 with margin, tons
W4	weight group 4 with margin, tons
W5	weight group 5 with margin, tons
W6	weight group 6 with margin, tons
W7	weight group 7 with margin, tons.

3.15 Subroutine SEASPD

3.15.1 Introduction

This routine is based on the work of Michael Shen, Peter Gale and Kenneth Walker as reported in References 4 and 5. In these references is given a computer program for computing the average sea speed. This computer program was altered by dropping the option to use a bow sonar dome and by deleting the read and write statements. The program was also rewritten in ASA standard FORTRAN. Except for these changes, subroutine SEASPD is the computer program developed by these three men. The interested reader is referred to these references for the development of the routine.

Briefly, the routine assumes: (1) that the ship is operating in the North Atlantic Ocean over a long period of time; (2) that it is steaming into head seas one half of the time; (3) that the remainder of the time (when steaming at other headings) it is not forced to reduce speed due to ship motions. Part of the time the ship is steaming into head seas, its speed will be limited be the sea state. In the routine this is simplified to a single sea state limited speed. The remainder of the time the ship is assumed to be able to make its maximum sustained speed. The percentage of the time the ship is limited in speed is estimated based on average wave heights in the North Atlantic Ocean and on ship characteristics.

The average speed at sea is calculated assuming that the vessel will travel at its maximum sustained speed whenever it is not limited in speed by the sea state. When the vessel is steaming at headings other than into head seas, its speed is not limited. This is assumed to be one half the time. When steaming into head seas its speed will be limited only part of the time. Both the limiting speed and the percentage of time that it applies are calculated in SEASPD.

This routine has been included to indicate the effect that changes in the vessels characteristics will have on its seakeeping ability. The many assumptions made in deriving the average sea speed make the speed predicted practically meaningless. However, the speed calculated can be used to compare two designs to decide which will give the better sea keeping performance.

A flow chart for this routine is shown in Figure 46.

3.15.2 Input List for Subroutine SEASPD

B.............LC(GG)	DPTRY...........LC(GG)
CP............LC(GG)	H...............LC(GG)
CWP...........LC(GG)	LBN.............LC(BB)
CX............LC(GG)	VSUS............LC(CC)

3.15.3 Statement Descriptions

For a detailed discussion of this routine see References 4 and 5.

SEASPD SUBROUTINE FLOW -CHART

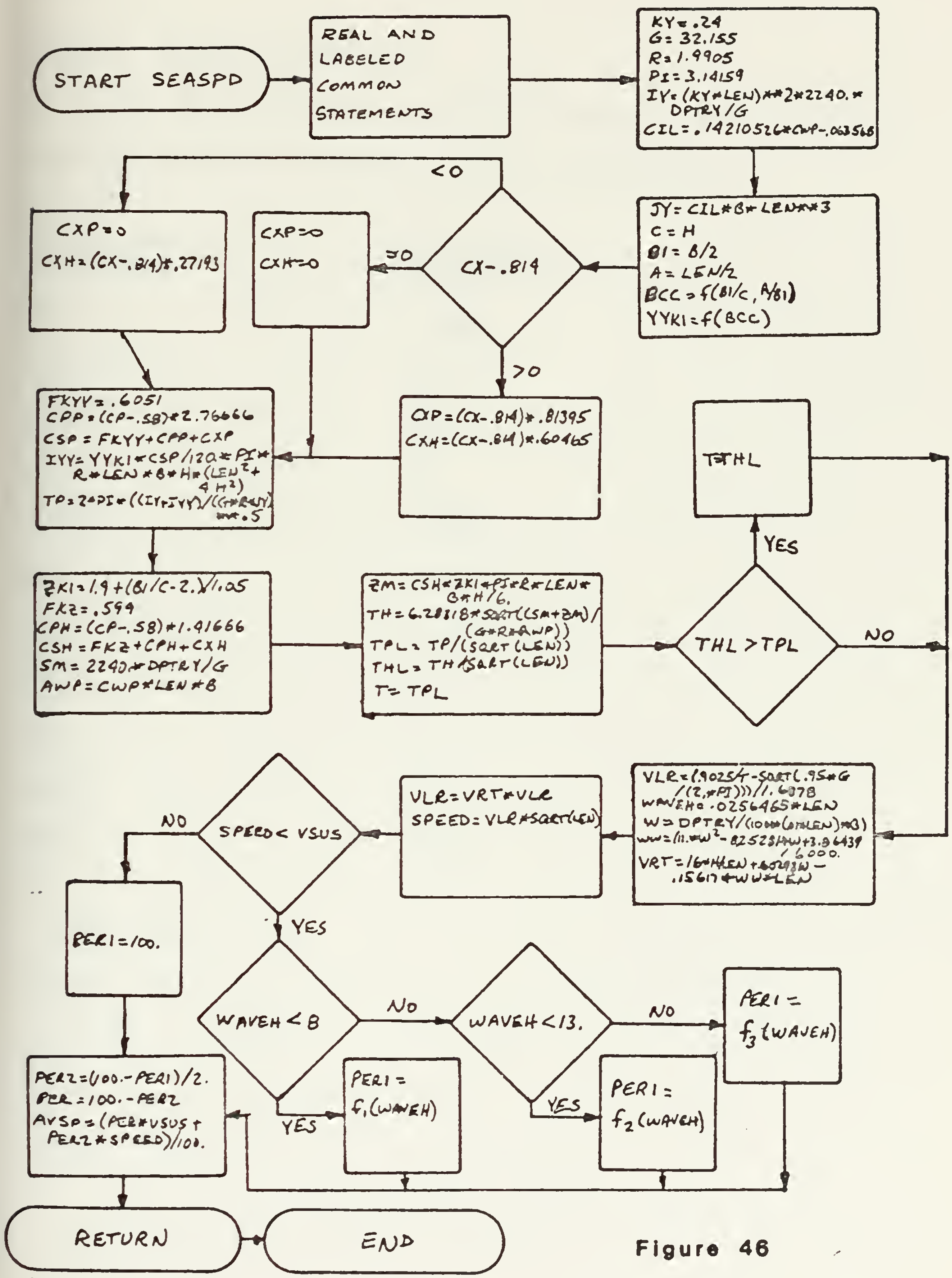


Figure 46

3.15.4 Output for Subroutine SEASPD

The only output is the value of average sea speed, AVSP.

3.15.5 Nomenclature List

The definitions used are the same as those given in References 4 and 5 except for the following:

Value used in SEASPD	Value used in references
B	BEAM
LEN	SL
CWP	CW
B1	B
DPTRY	DISPO
KY	DKY
IYY	YYI
JY	YJ
IY	YI
VSUS	VVV
VLR	VPX

3.16 Subroutine OUTPUT

3.16.1 Introduction

All program output is printed by subroutine OUTPUT except for error messages. A simplified flow chart for this routine is shown in Figure 47. Subroutine OUTPUT is divided into two main parts. The first prints the input data and the second prints the output generated.

If an error message is printed, only part of the output data is available and the data that is available is probably not correct. Therefore, when an error message occurs, only the input data is printed. Variable I1 has a value of 1 in this case. If the program successfully completes all preceeding steps, I1 is assigned a value of 2 and output data is also printed.

Subroutine OUTPUT consists primarily of write and format statements. Some calculations are made but only to convert previously calculated values to a desired output form such as determining ratios between weight groups and full load weight.

Only two decision points are used. One is the decision on whether or not to print output. The other checks the option used for inputting vehicle performance data and chooses the correct set of write and format statements to print the input data.

3.16.2 Input for Subroutine OUTPUT

All values which are printed are inputs to this routine.

OUTPUT SUBROUTINE
FLOW CHART

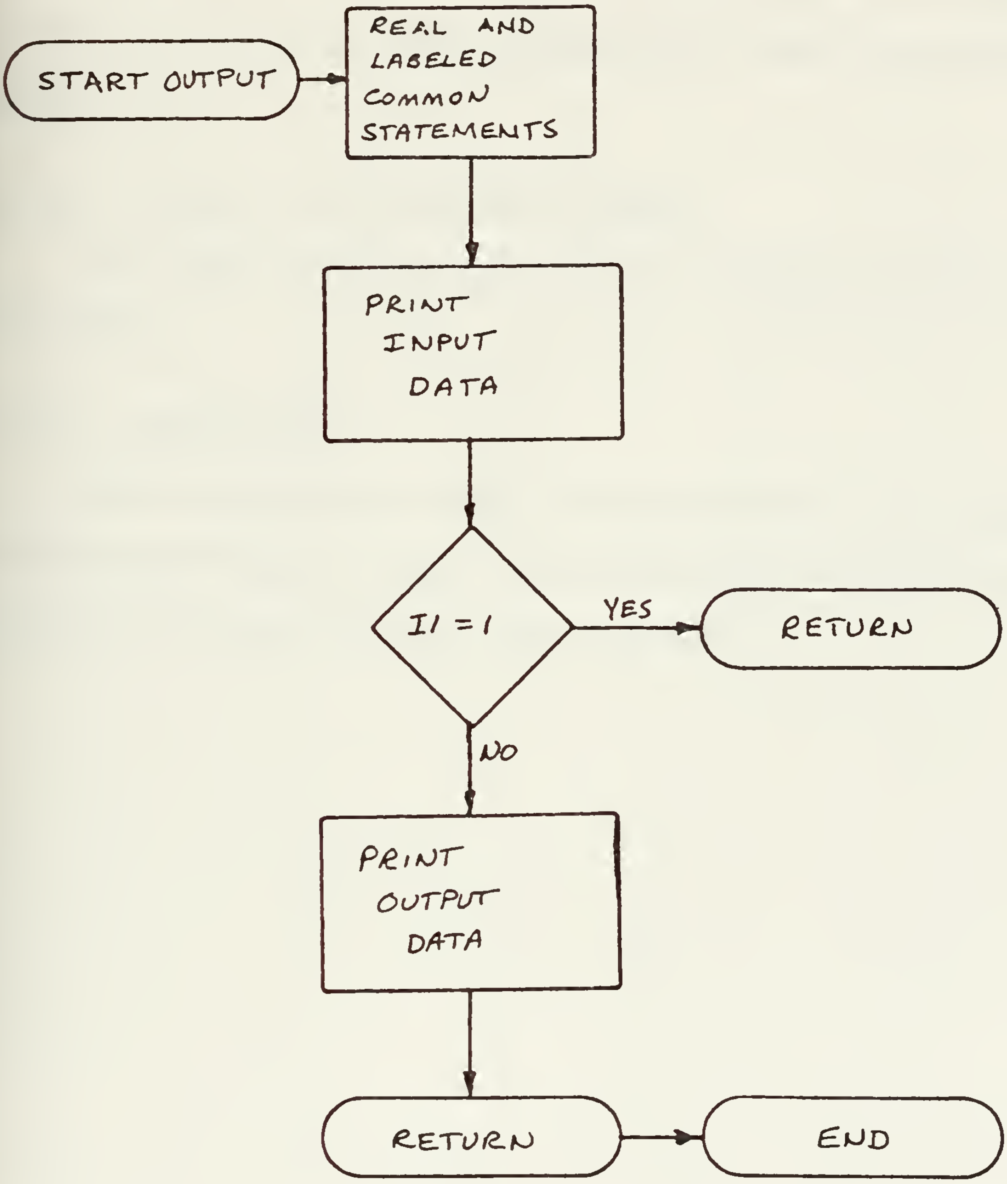


Figure 47

3.16.3 Statement Descriptions

Detailed descriptions of the statements of this routine will not be given since most of the statements are self-explanatory. Use of the sample outputs given in Appendix B will be of use in understanding the format statements used.

3.16.4 Output for Subroutine OUTPUT

No values are generated in this routine for use elsewhere.

3.16.5 Nomenclature

All the variables used in this routine have been defined previously except for some dummy variables whose definition should be clear from context.

CHAPTER IV

EVALUATION OF THE PROGRAM

A number of test runs were made on an IBM 370, model 168, computer located in the Information Processing Center at M.I.T. The test runs were made using input data for four existing designs, the 378' WHEC, the 210' WMEC, the 150' WPB, and the Navy's Patrol Frigate design. The Cutter Model produces feasible designs for each of these ships except the 150' WPB.

The design for the 150' WPB failed because a raised deck length greater than the ship length was required. The actual ship does not have a raised deck. The probable cause of this failure lies with the available area and volume relations used in the program. These relations were developed for ships with lengths greater than 400 feet and probably have significant errors when extended to ships as short as 150 feet. Recommendations for correcting this error are given in Chapter V.

A comparison between the results produced by the Cutter Model and the actual ships are shown in Tables 6a and 6b for the 378' WHEC and in Tables 7a and 7b for the 210' WMEC. The differences are reasonably small in most areas; however, a few do need discussion.

The largest difference with both ships occurs in

Table 6a

Comparison of Cutter Model Output to the Actual Ship for a 378' WHEC

	L_{bp} ft	Beam ft	Draft ft	D0 ft	D10 ft	D20 ft	Davg ft	Disp. tons
Ship	350.	42.0	14.3	34.75	27.25	27.5	28.54	2968.0
Model	350.	43.32	14.6	38.33	27.83	28.18	29.64	3061.5

	WEIGHTS		VCG	
	Ship	Model	Ship	Model
WTG1	917.46	962.8	19.12	19.42
WTG2	383.6	383.6	11.45	11.52
WTG3	88.12	164.8	23.49	21.76
WTG4	80.2	80.2	31.56	32.52
WTG5	268.8	262.3	19.43	19.76
WTG6	325.1	322.3	25.63	25.88
WTG7	39.0	39.0	35.26	36.30
WTLSHIP	2102.2	2215.0	19.72	19.98
FUEL	661.8	653.2	7.67	8.35
LUB OIL	13.7	16.0	3.58	3.62
CREW	} 22.03	13.7	} 26.26	27.00
PER EFFECTS		7.8		27.00
PER STORES	107.4	95.1	11.35	14.36
CARGO	0.	0.		
AMMO	37.5	37.5	15.99	16.42
AIRCRAFT	3.4	3.4	39.01	40.08
A/C FUEL	19.6	19.6	9.56	9.74
WTFLLD	2967.6	3061.4	16.61	17.20

Table 6b

Comparison of Cutter Model Output to the Actual Ship for a 378' WHEC

	Ship	Model	
Hull Volume	277600	273734	cu ft
Deckhouse Volume	95611	94705	cu ft
Total Arrangements Area	30863	29664	sq ft
Hull Arrangements Area	19615	18522	sq ft
Deckhouse Arrangements Area	11248	11142	sq ft
Office Space	493	510	sq ft
Messing Facilities	2713	2713	sq ft
Crew Special	725	787	sq ft
Officer S.R.	1157	1168	sq ft
Officer Sanitary	243	192	sq ft
CPO S.R.	1040	1040	sq ft
CPO Sanitary	250	208	sq ft
Crew Berthing	3641	3168	sq ft
Crew Sanitary	716	720	sq ft
CO S.R., Cabin & Pantry	755	753	sq ft
Commissary Stores	600	652	sq ft
Other Stores	3015	3231	sq ft
Workshops	1161	1254	sq ft
Repair Lockers	148	100	sq ft
Chain Lockers	47	40	sq ft
Uptakes	462	0*	sq ft
Steering Gear & Windlass	736	779	sq ft
A/C & Fan Spaces	369	396	sq ft
I.C. Spaces	312	312	sq ft
Aux. Machinery Spaces	1860	2180	sq ft
Pilot house, Chartroom & CIC	1125	1111	sq ft
Passages	2567	2450	sq ft
Input Area	5283**	5900	sq ft
Excess Area	1445	0	

* 460 sq ft included in input area

** Excess area was used for crew rec. rooms

Table 7a

Comparison of Cutter Model Output to the Actual Ship for a 210' WMEC

	L_{bp} ft	Beam ft	Draft ft	D0 ft	D10 ft	D20 ft	Davg ft	Disp. tons
Ship	200.	34.00	10.5	20.75	19.50	20.90	26.91	990.0
Model	200.	35.02	8.98	21.50	19.50	19.70	24.97	959.1

	WEIGHTS		VCG	
	Ship	Model	Ship	Model
WTG1	379.5	347.8	16.4	13.92
WTG2	102.6	102.6	9.5	9.55
WTG3	43.7	75.4	17.5	22.28
WTG4	26.1	26.1	34.2	33.31
WTG5	110.4	109.6	16.6	19.88
WTG6	104.4	106.8	22.6	25.93
WTG7	8.5	8.5	23.4	23.21
WTLSHIP	775.2	776.8	17.1	17.40
FUEL	152.3	137.3	8.17	8.40
LUB OIL	3.8	3.9	2.5	2.54
CREW	} 8.6	5.5	20.43	18.92
PER EFFECTS		3.2	20.43	18.92
PER STORES	47.3	30.4	10.99	11.95
CARGO	0.	0.		
AMMO	2.6	2.6	8.4	8.00
AIRCRAFT	0.	0.		
A/C FUEL	0.	0.		
WTFLLD	990.0	959.5	15.38	15.87

	Ship	Model
Raised Deck Length	164.	120.

Table 7b

Comparison of Cutter Model Output to the Actual Ship for a 210' WMEC

	Ship	Model	
Hull Volume	124700	123049	cu ft
Deckhouse Volume	16100	17840	cu ft
Total Arrangements Area	11242	11021	sq ft
Hull Arrangements Area	9345	8922	sq ft
Deckhouse Arrangements Area	1897	2099	sq ft
Office Space	130	192	sq ft
Messing Facilities	1452	1381	sq ft
Crew Special	324	313	sq ft
Officer S.R.	567	657	sq ft
Officer Sanitary	193	108	sq ft
CPO S.R.	283	320	sq ft
CPO Sanitary	75	64	sq ft
Crew Berthing	1658	1254	sq ft
Crew Sanitary	384	285	sq ft
CO S.R., Cabin & Pantry	406	398	sq ft
Commissary Stores	480	393	sq ft
Other Stores	1294	1233	sq ft
Workshops	544	382	sq ft
Repair Lockers	110	100	sq ft
Chain Lockers	42	40	sq ft
Uptakes	0	0	
Steering Gear & Windlass	270	390	sq ft
A/C & Fan Spaces	165	151	sq ft
I.C. Spaces	180	180	sq ft
Aux. Machinery Spaces	820	832	sq ft
Pilot house, Chartroom & CIC	422	486	sq ft
Passages	739	910	sq ft
Input Area	704	704	sq ft
Excess Area	0	247	sq ft

weight group 3, electric plant. This difference results from the fact that greater generating capacity relative to the average load has been built into the model than is installed in existing ships. This increase in generating capacity reflects current Coast Guard policy for new designs and is not an error in the program.

The differences in weight group 1 reflect the fact that the hull dimensions are not exactly the same for the program designs and the actual ships. Weight group 1 is a function primarily of the hull cubic number.

The fuel weight is calculated in the program based on specific fuel consumption, endurance range and endurance speed. An attempt has been made to approximate the actual fuel weight by varying one or more of these quantities but an exact match is difficult to obtain.

The only other significant weight difference occurs in personnel stores which includes potable water. The model results are less than the weights for the actual ships due to the fact that the amount of potable water per man has been reduced from the amount used on past designs. This is in accordance with current Coast Guard policy for future designs.

The vertical centers of gravity show quite a bit of variation when compared to the actual ships. However, the values in the program are only average values and will in general not agree with the values for any one ship.

In the case of the 210' WMEC, a raised deck is required. The model predicted a raised deck length 44 feet shorter than that of the actual ship. This is another indication that the available area and volume relations are inaccurate for smaller ships.

Hull areas are given in Tables 6b and 7b. The areas used in the cutter model for berthing and sanitary spaces are based on current minimum Coast Guard standards. These areas in general are lower than the areas on current ships.

Several runs were also made using data for the Navy's Patrol Frigate design. At the same time, runs were made on the Navy's destroyer model, DD07, using similar data. The results of these runs are shown in Tables 8 and 9.

The Patrol Frigate design is of interest because it is at the lower limit of applicability for the destroyer model and at the upper limit of applicability for the cutter model. Agreement between the values calculated by the two models and the actual ship as shown in Table 8, is reasonably good. Again, the group 3 weight is highest for the cutter model because 3 - 2000 KW generators are used instead of the 3 - 1000 KW generators on the actual ship. Also, it appears that the greater emphasis placed on habitability by the Coast Guard is reflected in a greater group 6 weight.

Table 9 gives the displacements predicted for greater lengths than the actual ship length. As the ship length

Table 8

Comparison of Cutter Model Output to the Actual Ship and to DD07 Estimate for the Patrol Frigate Design

	L_{bp} ft	Beam ft	Draft ft	D0 ft	D10 ft	D20 ft	Davg ft	Disp. tons
Ship	408.	45.0	14.5					3517.
Model	405.	45.95	15.34	41.07	28.92	29.33	31.01	3706.1
DD07	405.	46.72	15.3	41.00	33.99	34.80	35.30	3766.3

WEIGHTS

	Ship	Model	DD07
WTG1	1222.36	1199.6	1331.2
WTG2	256.1	258.0	240.0
WTG3	155.36	211.2	156.6
WTG4	92.58	70.7	70.7
WTG5	351.3	317.5	381.3
WTG6	268.82	333.8	238.0
WTG7	95.68	85.7	85.7
WTLSHIP	2442.20	2637.4	2666.3
FUEL	830.0	818.7	845.3
LUB OIL	20.22	20.2	0.6
CREW & PE	20.96	20.9	20.9
PER STORES	68.05	66.6	84.0
CARGO	67.0	75.0	80.9
AMMO	58.8	58.8	58.8
AIRCRAFT	10.0	10.0	10.0
A/C FUEL	0.	0.	0.
WTFLLD	3517.	3707.7	3766.9

Table 9

PATROL FRIGATE

Full Load Displacement vs. Length Estimates

L_{bp}	Displacement	
	DD07	Cutter Model
405.	3766.3	3707.7
415.	3652.2	3679.5
425.	3537.1	3672.0
435.	3401.6	3696.0
445.	3458.8	3764.1
455.	3529.2	3874.7
465.	3640.5	3985.9

is increased, the displacements predicted by the cutter model begin to diverge from those predicted by DD07. This indicates that the cutter model begins to lose accuracy for ship lengths above 400 feet, the assumed upper limit of the cutter model. Table 9 also shows that the two models predict different optimums. This is a result of the assumptions built into the two models.

CHAPTER V

RECOMMENDATIONS AND CONCLUSIONS

For the 378' WHEC and 210' WMEC, the full load displacements predicted by the cutter model are within four percent of the actual full load displacements of these two vessels. This is better accuracy than is obtainable with other currently available models for the size range of Coast Guard vessels. However, only a limited number of designs were used to develop the cutter model and these same designs were used to check it. The program should be used with caution until other designs are available to confirm the relationships used in the model.

Although the cutter model appears to give accurate results in its current form, there are several areas where significant improvements could be made. The two most important improvements are: (1) development of available arrangement area and volume relationships which are more applicable to ships of the size range used in the model and (2) expansion of the C_r array used in calculating horsepower requirements. The electrical generator sizing criteria should also be given careful consideration to determine if the sizes which result are what is really desired.

The development of area and volume relationships

will require considerable developmental work. As a minimum, the variation of area with hull depth, beam, C_p, C_x, tankage volume, and machinery box length must be considered. A computer program should be developed to calculate tankage volume and arrangements area for systematic changes in these variables. The results could then be converted into formulas for use in the cutter model.

The expansion of the C_r array could probably best be accomplished by fairing data from another model test series, such as series 64, into the data from Taylor's Standard Series. Where necessary some data may have to be assumed that is not available. An expansion of the array to speed length ratios of 3.0 and C_v values up to 0.008 would be very desirable. With the current array limits, many ships can not be run which may be very desirable. Also, if the sustained horsepower is given as an input, there are many times when the array limits are exceeded during an iteration even though the final speed value may be well within the limits of the array.

Finally, the generator capacity predicted by the model appears to be excessive. This criteria should be given careful consideration. Existing 378' WHEC cutters seldom exceed the capacity of one 500 KW generator in normal steaming; however, the criteria built into the cutter model would result in 1500 KW generator sets being

installed.

Some general recommendations on the use of the model are also in order. First, a ship synthesis model is only a design tool. Complete reliance should never be placed on a model; but, if checked by hand calculations, the model will greatly inhance the engineer's ship design capability. Also, as a tool, the model must be kept current. This implies that periodic reviews must be made of the empirical relations used to insure that they are in agreement with current policy. Every new design built should also be plotted on the curves included in Chapter III as additional data. Changes should be made if the new data is not in agreement with the old.

It is expected that the model will most often be used for designing new ships. Studied most often will probably be changes in length and C_p. These values have been arranged so that this can be done by changing only one input card. However, changes in any of the input variables can be investigated.

If the model is used to investigate the sensitivity to changes in the design assumptions, it will be necessary to change statements in the program itself. If many of these studies are being performed, some of the fixed values in the program could be read in on input cards.

One constraint on all ship synthesis models is that variations in hull form can not be investigated. If hull forms much different from those of current designs are

desired, a new model has to be developed. It must be remembered that a ship synthesis model is really a multi-dimensional linearization of a complex problem. If large departures are made from the data base designs, the errors will increase in magnitude.

Finally, the cutter model could be programmed as part of a ship optimization routine, but it is recommended that this not be done. Such a procedure puts the designer out of a controlling position while putting total reliance on an optimization criteria. Optimization criteria are difficult to define if more than just the cost of the vessel is in question. It is felt that such questions as the balance between payload and cost are best left to the designer and not to a rigid formula.

REFERENCES

1. Mills, J. Feasibility Studies and Ship Synthesis Models. Lectures 7, 8, and 9. Unpublished lecture notes for Professional Summer at M.I.T.

2. Hildebrand, F.B. Introduction to Numerical Analysis. New York: McGraw-Hill Book Company, 1956.

3. Comstock, John P., ed. Principles of Naval Architecture. New York: The Society of Naval Architects and Marine Engineers, 1967.

4. Shen, Michael and Peter Gale A Procedure for Predicting the Speed of Surface Ships in Rough Head Seas. Naval Ship Engineering Center Report No. 6114-71-4, 1970.

5. Shen, Michael, Peter A. Gale and Kenneth Walker An Improved Procedure for Predicting the Speeds of Surface Ships in Rough Head Seas. Naval Ship Engineering Center Report No. 6114-71-8, 1970.

6. U.S. Coast Guard Cost Estimating Procedure, "Flanagan's Method", U.S. Coast Guard Technical Files, Washington, D.C.

7. Gertler, Morton A Reanalysis of the Original Test Data for the Taylor Standard Series. David W. Taylor Model Basin Report 806, Washington, D.C.: U.S. Government Printing Office, 1954.

8. Mills, J. Personal notes on hull subdivision for destroyer type hulls

APPENDIX A

DESCRIPTION OF INPUT

APPENDIX A

Description of Input

Input for the cutter model can be divided into two main groups. The first group contains the data for the C_r arrays used in estimating propulsion power. The second group contains the data for individual ships that are run.

Data for the C_r arrays is read only once regardless of how many test cases are run. This data precedes all other data and the values never change. The C_r array data can be stored on tape or disk if desired. A list of the values used is given in Appendix D.

The second group of data allows the user to specify the payload and performance as well as various other parameters of the ship the computer is to design. In order for the computer to produce reliable results, the input data must be the best that it is possible to specify. Past designs are a good starting point for determining reasonable input values.

The minimum number of data cards for the second group of input is 14. These cards are described below. Where more than one card may be used this fact is noted.

Card 1 -- A single number is entered on this card in card column 1. The values that can be used are:

0 - the program will stop

1 - this is the normal value to use

2 - a fine hull form will be assumed for the first iteration, C_v = .0025.

Card 2 -- This card contains a heading that is printed above the output. All 80 columns can be used for any alphanumeric description desired.

Card 3 -- A single value is entered in card column 2. The total number of armament, aircraft and cargo payload data cards should be entered. A maximum of 20 can be used.

Card 4 -- This is really a set of cards containing the armament, aircraft and cargo payload data. The number of cards used is specified on card 3. Each of these cards has the following format: (All data should contain a decimal point)

columns 1--20 Any alphanumeric title describing the remainder of the data on the card.

columns 21-25 Cargo weight, enter the weight in tons.

columns 26-30 Cargo vcg, enter the ratio of cargo vcg divided by the depth of the ship at amidships.

columns 31-35 Group 7 weight, enter weight in tons.

columns 36-40 Group 7 vcg, enter ratio of kg to depth at amidships.

columns 41-45 Ammunition weight, enter weight in tons..

columns 46-50 Ammunition vcg, enter ratio of kg to depth at amidships.

columns 51-55 Aircraft weight, enter weight in tons.

columns 56-60 Aircraft vcg, enter ratio of kg to depth at amidships.

columns 61-65 Electrical load, enter value in KW.

columns 66-70 Deckhouse Area, enter area required to be in deckhouse in sq. ft.

columns 71-75 Hull Area, enter all remaining required area in sq. ft.

columns 76-80 Group 7 cost, enter acquisition cost in thousands of dollars.

Except for the moment arms, the values given on these cards are summed by category and only this sum is used in calculations. Therefore it does not matter whether all the data is given on one card or on several. The only requirement is that the vcg values apply to the weights which immediately precede them. All values which are included in light ship weight group 7 must be given as data on these cards.

If there is no payload data, card 3 should

contain a 1 and a blank card should be included for card 4.

Card 5 -- A single value is entered in card column 2. This is a count of the number of data cards described under card 6. A maximum of 20 can be used.

Card 6 -- This is really a set of electronics input data cards up to a maximum of 20. The number of cards is specified by card 5. Each of these cards has the following format: (All data should contain a decimal point)

columns 1--20 Any alphanumeric title describing the remainder of the data on the card.

columns 21-25 Group 4 weight, enter weight in tons.

columns 26-30 Group 4 vcg, enter ratio of kg to depth at amidships.

columns 31-35 Electrical load in KW.

columns 36-40 Deckhouse area, enter area required to be in deckhouse in sq. ft.

columns 41-45 Hull area, enter remaining required area in sq. ft.

columns 46-50 Group 4 cost, enter acquisition cost in thousands of dollars.

Again the data may be broken up in any way desired as long as the correct sets of

weight and vcg are given. On all of these cards and on the cards described under card 4, the area given under deckhouse area should included only the area that is required to be in the deckhouse. If an area can be either in the deckhouse or in the hull, it should be listed under hull area.

All items included in light ship weight group 4 must be entered on these cards. This includes standard navigation equipment. If there is no electronics data, card 5 should contain a 1 and a blank card should be included for card 6.

Card 7 -- The number of officers, CPOs and crew members are specified on this card. All numbers must be right-justified integers.

columns 1---5 number of officers
columns 6--10 number of chief petty officers
columns 11-15 number of enlisted men

Card 8 -- This card contains cost indices input. All values should contain a decimal point.

columns 1---5 labor rate in dollars/hour
columns 6--10 group 1 index
columns 11-15 group 2 index
columns 16-20 group 3 index
columns 21-25 group 5 index
columns 26-30 group 6 index

The values of the labor rate and cost indices may be found under Section 3.14, Figures and .

Card 9 -- The number of endurance days for dry provisions and aircraft fuel payload are given on this card. All values should contain a decimal point.

columns 1---5 endurance days for dry provisions

columns 6--10 weight of aircraft fuel, tons

columns 11-15 vcg of aircraft fuel, enter the ratio of kg to depth at amidships.

Card 10 -- A single value is entered in card column 2. Two options are available. If a 1 is entered, use card 11a. This option allows the user to input sustained speed and have the computer calculate horsepower. If a 2 is entered use card 11 b. Here particulars of the machinery plant are input and the sustained speed is calculated. Any other value will have an unknown effect.

Card 11a -- Use this card type if a value of 1 is entered on card 10. The maximum sustained speed, endurance speed and range and propulsive coefficients at endurance speed and maximum speed are entered on this card. All data should contain a decimal point.

columns 1---5 sustained speed in knots

columns 6--10 endurance speed in knots

columns 11-20 endurance range, nautical miles

columns 21-25 propulsive coef. at endurance speed

columns 26-30 propulsive coef. at maximum speed.

Card 11b -- Use this card type if a value of 2 is entered on card 10. The particulars of a specific machinery plant are entered on this card. All data should contain a decimal point.

columns 1---5 maximum sustained horsepower, enter as HP/1000

columns 6--10 minimum machinery box depth in feet

columns 11-15 machinery box length in feet

columns 16-20 total weight of group 2, tons

columns 21-25 specific fuel consumption at max. horsepower in lbs/HP-hr

columns 26-30 specific fuel consumption at half power in lbs/HP-hr

columns 31-35 endurance speed in knots

columns 36-45 endurance range, nautical miles

columns 46-50 propulsion auxiliaries electrical load in KW

columns 51-55 propulsive coef. at endurance speed

columns 56-60 propulsive coef. at maximum speed

columns 61-65 acquisition cost of group 2, thousands of dollars

columns 66-70 lub oil weight in tons.

Card 12 -- This card contains various input options and dimensions. All values except the first should contain a decimal point.

columns 1---5 MTYPE, a right-justified integer is entered here.

If MTYPE = 0 the program returns to read a new card 1

If MTYPE = 1 a diesel plant is assumed if the machinery particulars have not been given

If MTYPE = 2 a CODOG plant is assumed

If card 10 contains a value of 2, any value of MTYPE except 0 may be used.

columns 6--10 free surface correction, enter value in feet. This doesnot have to be a positive number. A negative number can be interpreted as a KG below the average built into the program.

columns 11-15 length between perpendiculars, enter the ships length in feet.

columns 16-20 C_p, enter a value for prismatic coefficient

columns 21-25 C_x, enter a value for midship section coefficient

columns 26-30 GM/Beam, a value of 0.1 is commonly used

columns 31-35 design and builders margin, enter a value as a decimal, i.e. a 10% margin is entered as 0.1

columns 36-45 ΔC_f, this is the frictional resistance correction used in horsepower calculations. A value of 0.0004 is commonly used.

Card 12 may be repeated as many times as desired with new data each time. Each new card is interpreted as a new data case.

Card 13 -- If it is desired to input an entirely new set of payload and performance data or to stop, a value of 0 should be given in column 5 of card 12. This will cause a new card 1 to be read.

Card 14 -- A new card 1 must be included. If new data will be given all of the data cards must be repeated. A value of 0 on card 1 will cause the program to stop.

A sample listing of the group 2 data cards is given below. The data used refers to a 210' WMEC.

Card 1

```
1
```

Card 2

```
  210 WMEC TEST RUN
```

Card 3

```
 5
```

Card 4

```
Group 700                4.7 1.64                        385.  76.
Group 701                 .6 1.01
Group 702                2.8  .60
Group 750                 .4  .31
Ammunition                         2.56  .41
                           '    '    '    '              '     '
             columns      35   40   45   50             75    80
```

Card 5

```
 6
```

Card 6

```
Group 400       .7 1.8521.99 319.     190.
Group 401      2.4 1.3
Group 402       .2 1.56
Group 403     10.4  .92
Group 404      9.1 2.69
Group 450      3.3 1.76
                 '    '    '    '         '
      columns   25   30   35   40        50
```

Card 7

```
    9    8   57
    '    '    '
    5   10   15 - columns
```

Card 8

```
 4.75  1.4  1.6 1.19 1.55 1.39
    '    '    '    '    '    '
    5   10   15   20   25   30 - columns
```

Card 9

```
 60.    0.    0.
   5   10    15 - columns
```

Card 10

```
 2
```

Card 11b

```
 4.5  19.   32.102.6   .42   .44   14.   4000.  .71  .55   .6 599.  3.85
   5   10    15    20    25    30    35     45   50   55   60    65    70
```

Card 12

```
   1-1.61 200.   .59 .892   .1    0.     .0004
   5   10    15    20    25    30    35      45 - columns
```

Card 13

```
   0  in column 5
```

Card 14

```
0  in column 1
```

APPENDIX B

SAMPLE OUTPUT

SUSTAINED SPEED ESTIMATING RUN 3/3/75 378' CUTTER DATA

*****INPUT DATA*****

ARMAMENT, AIRCRAFT AND CARGO INPUTS

ITEM	CARGO WEIGHT	CARGO VCG	GROUP 7 WEIGHT	GROUP 7 VCG	AMMO WEIGHT	AMMO VCG	AIRCRAFT WEIGHT	AIRCRAFT VCG	ELECT LOAD	AREA IN DECKHSE	AREA IN HULL	GROUP 7 COST
GROUP 700	0.0	0.0	29.7	1.450	0.0	0.0	0.0	0.0	46.640	1409.	2256.	196000.
GROUP 701	0.0	0.0	2.3	0.729	0.0	0.0	0.0	0.0	0.0	0.	0.	0.
GROUP 702	0.0	0.0	4.5	0.808	0.0	0.0	0.0	0.0	0.0	0.	0.	0.
GROUP 750	0.0	0.0	2.1	0.925	0.0	0.0	0.0	0.0	0.0	0.	0.	0.
GROUP 751	0.0	0.0	0.4	1.260	0.0	0.0	0.0	0.0	0.0	0.	0.	0.
AIRCRAFT	0.0	0.0	0.0	0.0	0.0	0.0	3.4	1.440	0.0	0.	0.	0.
AMMUNITION	0.0	0.0	0.0	0.0	37.5	0.590	0.0	0.0	0.0	0.	0.	0.
UPTAKES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.	460.	0.

ELECTRONICS INPUT

ITEM	GROUP 4 WEIGHT	GROUP 4 VCG	ELECT LOAD	AREA IN DECKHSE	AREA IN HULL	GROUP 4 COST
GROUP 400	10.6	0.835	117.800	1307.	468.	2228000.
GROUP 401	21.0	1.050	0.0	0.	0.	0.
GROUP 402	10.2	1.420	0.0	0.	0.	0.
GROUP 403	9.2	0.967	0.0	0.	0.	0.
GROUP 404	23.8	1.406	0.0	0.	0.	0.
GROUP 450	5.4	1.100	0.0	0.	0.	0.

MANNING INPUT

NO. OF OFFICERS = 16. NO. OF CPOS = 26. NO. OF ENLISTED MEN = 144.

COST INDICES INPUT

LABOR RATE = 4.75 DOLLARS/HR
GROUP 1 INDEX = 1.40
GROUP 2 INDEX = 1.60
GROUP 3 INDEX = 1.19
GROUP 5 INDEX = 1.55
GROUP 6 INDEX = 1.39

INDICES INCLUDE EFFECTS OF INFLATION AND SPECIAL MATERIAL COSTS

MILITARY MISSION CONSUMABLES INPUT

NO. ENDURANCE DAYS = 90. WEIGHT AIRCRAFT FUEL = 19.6 VCG AIRCRAFT FUEL = 0.350

VEHICLE PERFORMANCE INPUT
MAX SUSTAINED SPEED COMPUTED
MAX SUSTAINED SHP = 36000.
MIN DECKHEIGHT FOR MACHINERY = 22.00 FT
MIN LENGTH OF MACHINERY BOX = 53.00 FT
GROUP 2 WEIGHT = 383.6 TONS
SFC MAX POWER = 0.583 LBS/SHP-HR
SFC HALF POWER = 0.466 LBS/SHP-HR
ENDURANCE SPEED = 14.00 KTS
ENDURANCE RANGE = 10500. MILES
PROP AUX ELECT LOAD = 71.000 KW
PROP COEF ENDURANCE = 0.550
PROP COEF MAXIMUM = 0.600
GROUP 2 COST = 5952426. DOLLARS
WEIGHT OF LUB OIL = 16.0 TONS

OPTIONS

HTYPE = 2
FREE SURFACE CORRECTION = 0.0 FT
GM MULTIPLIER = 0.100
DESIGN AND BUILDERS MARGIN = 0.0
DELTA CP = 0.00040
LENGTH = 350.0 FT
CP = 0.582
CX = 0.820

*****OUTPUT*****

LENGTH	BEAM	DRAFT	DO	D10	D20	DAVG	LNTH BD	CP	CX	DISPLACEMENT	SHPMAX	VSUS	SHPEND
350.0	43.32	14.60	38.33	27.83	28.18	29.64	0.0	0.582	0.820	3061.5	36000.	26.44	2647.

AVERAGE SPEED IN SEAWAY IS 23.50 KNOTS

ELECTRIC PLANT CAPACITY/GEN = 1500. KW

	WEIGHTS	VCG	WT/WFULLD	WT/WLSHIP	COST
WTG1	962.8	19.425	0.314	0.435	2218029.
WTG2	383.6	11.523	0.125	0.173	5952426.
WTG3	164.8	21.755	0.054	0.074	2436464.
WTG4	80.2	32.520	0.026	0.036	2903021.
WTG5	262.3	19.762	0.086	0.118	3192438.
WTG6	322.3	25.883	0.105	0.146	4377166.
WTG7	39.0	36.296	0.013	0.018	354553.
WLSHIP	2215.0	19.981	0.724	1.000	29377856. = TOTAL COST
FUEL	653.2	8.350	0.213		
LUB OIL	16.0	3.618	0.005		
CREW	13.7	26.998	0.004		
EFF EFF	7.8	26.998	0.003		
PER STR	95.1	14.357	0.031		
CARGO	0.0	0.0	0.0		
AMMO.	37.5	16.422	0.012		
AIR CFT	3.4	40.080	0.001		
A/C FUEL	19.6	9.742	0.006		
WFULLD	3061.4	17.201			

A MARGIN ON KG OF 0.0 FT EXISTS ABOVE THE FULL LOAD KG VALUE GIVEN

NOTE D&B MARGIN INCLUDED IN WLSHIP AND COST ESTIMATES BUT NOT IN INDIVIDUAL WEIGHT GROUPS
OVERHEAD AND PROFIT ARE INCLUDED IN INDIVIDUAL WEIGHT GROUP COSTS
TOTAL COST INCLUDES A DESIGN COST OF 3305516. DOLLARS
A CONST SERVICES COST OF 939013. DOLLARS
AND A MISC. ITEM COST OF 3699262. DOLLARS
MISC.ITEM COST INCLUDES ORI OUTFIT, SPARES, RETROFIT COSTS, AND ADMINISTRATIVE COSTS(RIO)

VOLUME OF HULL = 273734. CU FT
VOLUME OF DECKHOUSE = 94705. CU FT

	VOLUME (CU FT)	VOL/ENCVOL
MACHINERY ROOM	57390.	0.156
TANKAGE	36987.	0.100
ARRANGEMENTS	274062.	0.744

TOTAL ARRANGEMENTS AREA = 29664.
HULL ARRANGEMENTS AREA = 18522.
DECKHOUSE ARRANGEMENTS AREA = 11142.

	AREA (SQ FT)	AREA/TOT AREA
OFFICE SPACE	510.	0.017
MESSING FACILITIES	2713.	0.091
CREW SPECIAL	787.	0.027
OFFICER S.R.	1168.	0.039
OFFICER SANITARY	192.	0.006
CPO S.R.	1040.	0.035
CPO SANITARY	208.	0.007
CREW BERTHING	3168.	0.107
CREW SANITARY	720.	0.024
C.O. S.R.,CABIN & PANTRY	753.	0.025
COMMISSARY STORES	652.	0.022
OTHER STORES	3231.	0.109
WORKSHOPS	1254.	0.042
REPAIR LOCKERS	100.	0.003
CHAIN LOCKER	40.	0.001
UPTAKES	0.	0.0
STEERING GEAR & WINDLASS	779.	0.026
A/C & FAN SPACES	396.	0.013
I.C. SPACES	312.	0.011
AUX MACHINERY SPACES	2180.	0.073
PILOT HOUSE,CHARTROOM & CIC	1111.	0.037
PASSAGES	2450.	0.083
INPUT AREA	5900.	0.199
EXCESS AREA	-1.	-0.000

CREW SPECIAL INCLUDES SICKBAY,BARBERSHOP,MOVIE LOCKER, LAUNDRY,AND SHIPS STORE

MAN VOL/MAN = 491.2 CUFT/MAN
GR2WT/HP = 0.0107 TONS/HP
MACH ROOM VOL/HP = 1.5942 CUFT/HP
GR1WT/ENCVOL = 0.00261 TONS/CUFT
WFULLD/ENCVOL = 0.03831 TONS/CUFT
WLSHIP/ENCVOL = 0.00601 TONS/CUFT
GR4COST/TOTCOST = 0.099
GR7COST/TOTCOST = 0.012
VCG/DAVG = 0.580

210 WMEC TEST RUN

*****INPUT DATA*****

ARMAMENT, AIRCRAFT AND CARGO INPUTS

ITEM	CARGO WEIGHT	CARGO VCG	GROUP 7 WEIGHT	GROUP 7 VCG	AMMO WEIGHT	AMMO VCG	AIRCRAFT WEIGHT	AIRCRAFT VCG	ELECT LOAD	AREA IN DECKHSE	AREA IN HULL	GROUP 7 COST
GROUP 700	0.0	0.0	4.7	1.640	0.0	0.0	0.0	0.0	0.0	0.	385.	76000.
GROUP 701	0.0	0.0	0.6	1.010	0.0	0.0	0.0	0.0	0.0	0.	0.	0.
GROUP 702	0.0	0.0	2.8	0.630	0.0	0.0	0.0	0.0	0.0	0.	0.	0.
GROUP 750	0.0	0.0	0.4	0.310	0.0	0.0	0.0	0.0	0.0	0.	0.	0.
AMMUNITION	0.0	0.0	0.0	0.0	2.6	0.410	0.0	0.0	0.0	0.	0.	0.

ELECTRONICS INPUT

ITEM	GROUP 4 WEIGHT	GROUP 4 VCG	ELECT LOAD	AREA IN DECKHSE	AREA IN HULL	GROUP 4 COST
GROUP 400	0.7	1.850	21.990	319.	0.	190000.
GROUP 401	2.4	1.300	0.0	0.	0.	0.
GROUP 402	0.2	1.560	0.0	0.	0.	0.
GROUP 403	10.4	0.920	0.0	0.	0.	0.
GROUP 404	9.1	2.690	0.0	0.	0.	0.
GROUP 450	3.3	1.760	0.0	0.	0.	0.

MANNING INPUT

NO. OF OFFICERS = 9.   NO. OF CPOS = 8.   NO. OF ENLISTED MEN = 57.

COST INDICES INPUT

LABOR RATE = 4.75 DOLLARS/HR
GROUP 1 INDEX = 1.40
GROUP 2 INDEX = 1.60
GROUP 3 INDEX = 1.19
GROUP 5 INDEX = 1.55
GROUP 6 INDEX = 1.39

INDICES INCLUDE EFFECTS OF INFLATION AND SPECIAL MATERIAL COSTS

MILITARY MISSION CONSUMABLES INPUT

NO. ENDURANCE DAYS = 60. WEIGHT AIRCRAFT FUEL = 0.0 VCG AIRCRAFT FUEL = 0.0

VEHICLE PERFORMANCE INPUT

MAX SUSTAINED SHP COMPUTED
SUSTAINED SPEED = 17.29 KTS
ENDURANCE SPEED = 14.00 KTS
ENDURANCE RANGE = 4000. MILES
PROP COEF ENDURANCE = 0.550
PROP COEF MAXIMUM = 0.600

OPTIONS

MTYPE = 1
FREE SURFACE CORRECTION = -1.61 FT
GM MULTIPLIER = 0.100
DESIGN AND BUILDERS MARGIN = 0.0
DELTA CP = 0.00040
LENGTH = 200.0 FT
CP = 0.590
CX = 0.892

*****OUTPUT*****

LENGTH	BEAM	DRAFT	DO	D10	D20	DAVG	LNTH BD	CP	CX	DISPLACEMENT	SHPMAX	VSUS	SHPEND
200.0	33.96	9.12	20.43	18.43	18.63	24.34	130.5	0.590	0.892	943.9	4412.	17.29	1554.

AVERAGE SPEED IN SEAWAY IS 14.55 KNOTS

ELECTRIC PLANT CAPACITY/GEN = 500. KW

	WEIGHTS	VCG	WT/WFULLD	WT/WLSHIP	COST
WTG1	334.5	13.355	0.354	0.444	943392.
WTG2	98.9	9.014	0.105	0.131	1050790.
WTG3	75.4	21.424	0.080	0.100	1051032.
WTG4	26.1	31.476	0.028	0.035	343885.
WTG5	104.2	19.118	0.110	0.138	1482397.
WTG6	105.8	24.928	0.112	0.140	1379934.
WTG7	8.5	21.935	0.009	0.011	127777.
WLSHIP	753.4	16.739	0.797	1.000	8521473. = TOTAL COST
FUEL	141.2	8.078	0.149		
LUB OIL	9.4	2.396	0.010		
CREW	5.5	17.874	0.006		
PER EFF	3.2	17.874	0.003		
FEB STR	30.4	11.439	0.032		
CARGO	0.0	0.0	0.0		
AMMO	2.6	7.555	0.003		
AIR CFT	0.0	0.0	0.0		
A/C FUEL	0.0	0.0	0.0		
WFULLD	945.6	15.118			

A MARGIN ON KG OF 0.0 FT EXISTS ABOVE THE FULL LOAD KG VALUE GIVEN

NOTE D&B MARGIN INCLUDED IN WLSHIP AND COST ESTIMATES BUT NOT IN INDIVIDUAL WEIGHT GROUPS
OVERHEAD AND PROFIT ARE INCLUDED IN INDIVIDUAL WEIGHT GROUP COSTS
TOTAL COST INCLUDES A DESIGN COST OF 797657. DOLLARS
A CONST SERVICES COST OF 382764. DOLLARS
AND A MISC. ITEM COST OF 961851. DOLLARS
MISC.ITEM COST INCLUDES OBI OUTFIT, SPARES, RETROFIT COSTS, AND ADMINISTRATIVE COSTS(RIO)

VOLUME OF HULL = 115869. CU FT
VOLUME OF DECKHOUSE = 17840. CU FT

	VOLUME (CU FT)	VOL/ENCVOL
MACHINERY ROOM	18167.	0.136
TANKAGE	16651.	0.125
ARRANGEMENTS	98891.	0.740

TOTAL ARRANGEMENTS AREA = 10661.
HULL ARRANGEMENTS AREA = 8562.
DECKHOUSE ARRANGEMENTS AREA = 2099.

	AREA(SQ FT)	AREA/TOT AREA
OFFICE SPACE	192.	0.018
MESSING FACILITIES	1381.	0.129
CREW SPECIAL	313.	0.029
OFFICES S.R.	657.	0.062
OFFICER SANITARY	108.	0.010
CIC S.R.	320.	0.030
CPO SANITARY	64.	0.006
CREW BERTHING	1254.	0.118
CREW SANITARY	285.	0.027
C.O. S.R.,CABIN & PANTRY	398.	0.037
COMMISSARY STORES	393.	0.037
OTHER STORES	1180.	0.111
WORKSHOPS	358.	0.034
REPAIR LOCKERS	100.	0.009
CHAIN LOCKER	40.	0.004
UPTAKES	65.	0.006
STEERING GEAR & WINDLASS	380.	0.036
A/C & FAN SPACES	144.	0.014
I.C. SPACES	180.	0.017
AUX MACHINERY SPACES	796.	0.075
PILOT HOUSE,CHARTROOM & CIC	469.	0.044
PASSAGES	881.	0.083
INPUT AREA	704.	0.066
EXCESS AREA	-0.	-0.000

CREW SPECIAL INCLUDES SICKBAY,BARBERSHOP,MOVIE LOCKER, LAUNDRY,AND SHIPS STORE

HAB VOL/MAN = 549.0 CUFT/MAN
GR2WT/HP = 0.0224 TONS/HP
MACH ROOM VOL/HP = 4.1175 CUFT/HP
GR1WT/ENCVOL = 0.00250 TONS/CUFT
WHULLD/ENCVOL = 0.00707 TONS/CUFT
WLSHIP/ENCVOL = 0.00563 TONS/CUFT
GR4COST/TOTCOST = 0.040
GR7COST/TOTCOST = 0.015
VCG/DAVG = 0.621

APPENDIX C

LISTING OF THE PROGRAM

```
      REAL LEN,KGTRY,NOFF,NCPO,NENL
      REAL LRD
      REAL MCST
      COMMCN/AA/ENDDAY,NCFF,NCPO,NENL
      COMMON/BB/CN,DHV,ENCVCL,DAVG,AREACH,AREAHL,LEN
      COMMON/CC/SHPM,SHPE,VSUS,VEND,RGEND,DELCF,SFCMHP,SFCHHP,MTYPE,JCPT
     1,PCM,PCE
      COMMON/CD/ELKW,AVGKW,ELOAD,BLOAD,PALOAD
      COMMON/EE/GR4WT(20),GR4CG(20),GR7WT(20),GR7CG(20),AMOWT(20),
     1AMOCG(20),ACWT(20),ACCG(20),           CARGOW(20),CARGOC(20)
      COMMCN/FF/TITLE(5,40),HEAD(20),NOARM,NOELT
      COMMON/GG/FRSC,CP,CX,GMMUL,KGTRY,DPTRY,B,H,CWP
      COMMON/HH/CGFUEL,CGLO,CGCREW,CGPE,CGPS,CCARGO,CGAMMO,CGAC,CACFUL
      COMMON/JJ/DHM,XLM,LRD
      COMMON/KK/ELLD(20),DHAR(20),HLAR(20),ELD(20),DHA(20),HLA(20)
     1,GR7CST(20),GR4CST(20)
      COMMCN/LL/WTFUEL,WTLO,WTCREW,WTPE,WTPS,WCARGO,WTAMMO,WTAC,WACFUL
      COMMON/MM/CSTG1,CSTG2,CSTG3,CSTG4,CSTG5,CSTG6,CSTG7,DCST,CCST,MCST
      COMMON/NN/ DOLHR,G1IND,G2IND,G3IND,G5IND,G6IND,TCTCST
      COMMON /TT/CR1(1152),CR2(972),CR3(216)
      COMMON/WW/WTG1,WTG2,WTG3,WTG4,WTG5,WTG6,WTG7,WLSHIP,WFULLD,DBMAR
      READ(8,120) CR1
  120 FORMAT(16F5.0)
      READ(8,121) CR2
  121 FORMAT(9F5.0)
      READ(8,122)CR3
  122 FORMAT(6F5.0)
    2 READ(8,124) INDEX
  124 FORMAT(I1)
      IF(INDEX.EQ.0) STOP
      READ(8,123)(HEAD(I),I=1,20)
  123 FORMAT(20A4)
C     ARMAMENT, AIRCRAFT ANC CARGO INPUT
      READ(8,100) NOARM
  100 FORMAT(I2)
      READ(8,101)((TITLE(J,I),J=1,5),CARGOW(I),CARGOC(I),GR7WT(I),GR7CG
```

```
     1(I),AMOWT(I),AMOCG(I),ACWT(I),ACCG(I),ELLD(I),DHAR(I),HLAR(I),          MAIN0037
     2GR7CST(I),I=1,NOARM)                                                   MAIN0038
 101 FORMAT(5A4,12F5.0)                                                      MAIN0039
     WCARGO=0.                                                               MAIN0040
     WTG7=0.                                                                 MAIN0041
     WTAMMO=0.                                                               MAIN0042
     WTAC=0.                                                                 MAIN0043
     ELOAD=0.                                                                MAIN0044
     BLOAD=0.                                                                MAIN0045
     AREADH=0.                                                               MAIN0046
     AREAHL=0.                                                               MAIN0047
     CSTG7=0.                                                                MAIN0048
     DO 10 I=1,NOARM                                                         MAIN0049
     WCARGO=WCARGO+CARGOW(I)                                                 MAIN0050
     WTG7=WTG7+GR7WT(I)                                                      MAIN0051
     WTAMMO=WTAMMO+AMOWT(I)                                                  MAIN0052
     WTAC=WTAC+ACWT(I)                                                       MAIN0053
     BLOAD=BLOAD+ELLD(I)                                                     MAIN0054
     GR7CST(I)=GR7CST(I)*1000.                                               MAIN0055
     CSTG7=CSTG7+GR7CST(I)                                                   MAIN0056
     AREADH=AREADH+DHAR(I)                                                   MAIN0057
  10 AREAHL=AREAHL+HLAR(I)                                                   MAIN0058
C    ELECTRONICS INPUT                                                       MAIN0059
     READ(8,102) NOELT                                                       MAIN0060
 102 FORMAT(I2)                                                              MAIN0061
     READ(8,103)((TITLE(J,I+20),J=1,5),GR4WT(I),GR4CG(I),ELD(I),DHA(I),      MAIN0062
    1HLA(I),GR4CST(I),I=1,NOELT)                                             MAIN0063
 103 FORMAT(5A4,6F5.0)                                                       MAIN0064
     WTG4=0.                                                                 MAIN0065
     CSTG4=0.                                                                MAIN0066
     DO 11 I=1,NOELT                                                         MAIN0067
     WTG4=WTG4+GR4WT(I)                                                      MAIN0068
     ELOAD=ELOAD+ELD(I)                                                      MAIN0069
     GR4CST(I)=GR4CST(I)*1000.                                               MAIN0070
     CSTG4=CSTG4+GR4CST(I)                                                   MAIN0071
     AREADH=AREADH+DHA(I)                                                    MAIN0072
```

```
   11 AREAHL=AREAHL+FLA(I)
      G4CST=CSTG4
      G7CST=CSTG7
C     MANNING INPUT
      READ(8,104) NOOFF,NOCPC,NOCREW
  104 FORMAT(3I5)
      NOFF=FLOAT(NOOFF)
      NCPO=FLOAT(NOCPC)
      NENL=FLOAT(NOCREW)
C     COST INDICES INPUT
      READ(8,110) DOLHR,G1INC,G2IND,G3IND,G5IND,G6IND
  110 FORMAT(6F5.0)
C     MILITARY MISSION CONSUMABLES INPUT
      READ(8,105) ENDDAY,WACFUL,CACFUL
  105 FORMAT(3F5.0)
      HPMS=0.
C     VEHICLE PERFORMANCE INPUT
      READ(8,106) JOPT
  106 FORMAT(I2)
C     (1 COMPUTE MAX HP, 2 COMPUTE SPEED)
      IF(JOPT.EQ.2) GOTO 1
      READ(8,107) VSUS,VEND,RGEND,PCE,PCM
  107 FORMAT(2F5.0,F10.0,2F5.0)
      GOTO 9
    1 READ(8,108) HPMS,DHM,XLM,WTG2,SFCMHP,SFCHHP,VEND,RGEND,PALOAD,PCE,
     1PCM,CSTG2,WTLO
  108 FORMAT(7F5.0,F10.0,5F5.0)
      HPMS=HPMS*1000.
      CSTG2=CSTG2*1000.
      GR2CST=CSTG2
C     OPTIONS
    9 READ(8,109) MTYPE,FRSC,LEN,CP,CX,GMMUL,DBMAR,DELCF
C     MTYPE = 1 DIESEL,MTYPE = 2 CODOG
  109 FORMAT(I5,6F5.0,F10.0)
      IF(MTYPE.EQ.0) GOTO 2
      DBMAR=1.+DBMAR
```

```
      CSTG2=GR2CST                                          MAIN0109
      CSTG4=G4CST                                           MAIN0110
      CSTG7=G7CST                                           MAIN0111
      KGTRY=LEN/(.0465*LEN+4.825)                           MAIN0112
      KGTRY=KGTRY-2.                                        MAIN0113
      DPTRY=(.006562-.001188*LEN/100.)*LEN**3/35.           MAIN0114
      IF(INDEX.EQ.2) DPTRY=.0025*LEN**3/35.                 MAIN0115
      CN=DPTRY*160.                                         MAIN0116
      CALL XECUTE(HPMS)                                     MAIN0117
      GOTO 9                                                MAIN0118
      END                                                   MAIN0119
```

```
      SUBROUTINE XECUTE(HPMS)
      REAL LEN,KGTRY
      COMMON/BB/CN,DHV,ENCVCL,DAVG,AREADH,AREAHL,LEN
      COMMON/CC/SHPM,SHPE,VSUS,VE,RE,DELCF,SFCM,SFCH,MTYPE,JOPT,PCM,PCE
      COMMON/GG/FRSC,CP,CX,GMMUL,KGTRY,DPTRY,B,H,CWP
      COMMON/WW/WTG1,WTG2,WTG3,WTG4,WTG5,WTG6,WTG7,WLSHIP,WFULLD,DBMAR
      EXCKG=0.
      JNDEX=1
      LNDEX=1
    7 CALL UWDIM(R)
      IF(LEN.LT.0.) GOTO 999
      IF(JOPT.EQ.2) GOTO 1
      CALL HPCALC(VSUS,SHP,PCM)
      IF(LEN.LT.0.) GOTO 998
      GOTO 2
    1 VMAX=(HPMS*200./LEN)**.33333
    4 CALL HPCALC(VMAX,SHP,PCM)
      IF(LEN.LT.0.) GOTO 998
      SHP1=SHP
      VMAX1=.95*VMAX
      CALL HPCALC(VMAX1,SHP,PCM)
      IF(LEN.LT.0.) GOTO 998
      SHP2=SHP
      DELHP=(SHP1-SHP2)/(VMAX-VMAX1)
      VMAX1=VMAX-(SHP1-.8*HPMS)/DELHP
      IF(ABS(VMAX1-VMAX).LE.VMAX1*.005) GOTO 3
      VMAX=VMAX1
      GOTO 4
    3 VSUS=VMAX1
      SHPM=HPMS
      GOTO 5
    2 SHPM=SHP/.8
      IF(MTYPE.EQ.1.AND.SHPM.GT.14000.) GO TO 997
    5 CALL HPCALC(VE,SHP,PCE)
      IF(LEN.LT.0.) GOTO 998
      SHPE=SHP
```

```
      CALL EPLANT                                                       XEC 0037
      CALL MACHLQ                                                       XEC 0038
      IF(JOPT.EQ.2) GOTO 6                                              XEC 0039
      CALL MBSIZE (B)                                                   XEC 0040
    6 CALL VOLUME                                                       XEC 0041
      IF(LEN.LT.0.) GOTO 996                                            XEC 0042
      CALL WEIGHT                                                       XEC 0043
      IF(ABS(WFULLD-DPTRY).LT.2.) GO TO 8                               XEC 0044
      IF(LNDEX.GE.2) GOTO 9                                             XEC 0045
      WT1=WFULLD                                                        XEC 0046
      DP1=DPTRY                                                         XEC 0047
      DPTRY=WFULLD                                                      XEC 0048
      GOTO 10                                                           XEC 0049
    9 FACTOR=(DPTRY-WFULLD-DP1+WT1)/(DPTRY-DP1)                         XEC 0050
      DP1=DPTRY                                                         XEC 0051
      WT1=WFULLD                                                        XEC 0052
      DPTRY=DPTRY-(DPTRY-WFULLD)/FACTOR                                 XEC 0053
   10 IF(LNDEX.GT.20) GOTO 995                                          XEC 0054
      LNDEX=LNDEX+1                                                     XEC 0055
      GOTO 7                                                            XEC 0056
    8 CONTINUE                                                          XEC 0057
      LNDEX=1                                                           XEC 0058
      CALL VCG(CFULLD)                                                  XEC 0059
      IF(ABS(CFULLD-KGTRY).LT..1) GOTO 11                               XEC 0060
      IF(JNDEX.GT.21) GOTO 994                                          XEC 0061
      IF(CFULLD.LT.KGTRY) GOTO 12                                       XEC 0062
   13 KGTRY=(CFULLD+KGTRY)/2.                                           XEC 0063
      JNDEX=JNDEX+1                                                     XEC 0064
      GOTO 7                                                            XEC 0065
   12 IF(R.LT..001) GOTO 13                                             XEC 0066
      EXCKG=KGTRY-CFULLD                                                XEC 0067
   11 CONTINUE                                                          XEC 0068
      CALL COST(LEN)                                                    XEC 0069
      CALL SEASPD(AVSP)                                                 XEC 0070
      CALL OUTPUT(AVSP,EXCKG,2)                                         XEC 0071
      RETURN                                                            XEC 0072
```

```
994 CALL OUTPUT(0.,0.,1)
    WRITE(5,106)
106 FORMAT(///' NO BALANCE BETWEEN ASSUMED AND CALC KG WITHIN 0.1 FEET
   1 COULD BE MADE IN 20 ITERATIONS'///)
    GOTO 1000
995 CALL OUTPUT(0.,0.,1)
    WRITE(5,105)
105 FORMAT(///' NO BALANCE BETWEEN WEIGHT AND DISPLACEMENT WITHIN 2
   1TONS COULD BE MADE IN 20 ITERATIONS'///)
    GOTO 1000
996 CALL OUTPUT(0.,0.,1)
    WRITE(5,104)
104 FORMAT(///' TOO LARGE A VOLUME REQUIRED FOR SOLUTION USING INPUT
   1LENGTH, TRY A LONGER SHIP'///)
    GOTO 1000
997 CALL OUTPUT(0.,0.,1)
    WRITE(5,103)
103 FORMAT(///' REQUIRED HP EXCEEDS STORED DATA. INPUT MACHINERY DATA
   1 USING JOPT=2'///)
    GOTO 1000
998 CALL OUTPUT(0.,0.,1)
    WRITE(5,101)
101 FORMAT(///' LIMITS OF STORED RESISTANCE DATA EXCEEDED'///)
    GOTO 1000
999 CALL OUTPUT(0.,0.,1)
    WRITE(5,100)
100 FORMAT(///' VCG IS ABOVE LIMITS OF STORED DATA'///)
1000 WRITE(5,102)
102 FORMAT(' PROGRAM PROCEEDING TO NEXT INPUT CASE'///)
    RETURN
    END
```

```
      SUBROUTINE UWDIM(R)
      REAL LEN
      DIMENSION A(5),B(5),C(5)
      COMMON/BB/CN,DPV,ENCVOL,DAVG,AREADH,AREAHL,LEN
      COMMON/GG/FRSC,CP,CX,C5,C4,DISPL,B1,H,CWP
      DPTRY=DISPL/1.014
      CWP=.8065*CP+.2645
      CALPH=.12*CWP-.0414
      C1=DPTRY*35./(LEN*CP*CX)
      C2=.833-CP*CX/(3.*CWP)
      C3=LEN*CALPH/(DPTRY*35.)
      C4=C4+FRSC
C     R=KB+BM-KG-FRSC-GM=C2*H+C3*B**3-C4-C5*B
C     H=C1/B
C     DR/DB=-C1*C2/B**2+3*C3*B**2-C5=0 FOR MINIMUM POINT
      BMIN=SQRT((C5+SQRT(C5**2+12.*C1*C2*C3))/(6.*C3))
      HMIN=C1/BMIN
      BTR=BMIN/HMIN
      IF(BTR.LT.2..OR.BTR.GT.4.) GOTO 1
      R=C2*HMIN+C3*BMIN**3-C4-C5*BMIN
      IF(R.LE.0.0) GOTO 2
      C4=C4-FRSC+R
      B1=BMIN
      H=HMIN
      RETURN
    1 HMAX=SQRT(C1/2.005)
      BMIN=C1/HMAX
      R=C2*HMAX+C3*BMIN**3-C4-C5*BMIN
      IF(R.LE.0.0) GOTO 2
      C4=C4-FRSC+R
      B1=BMIN
      H=HMAX
      RETURN
    2 HMIN=SQRT(C1/3.995)
      BMAX=C1/HMIN
      R=C2*HMIN+C3*BMAX**3-C4-C5*BMAX
```

```
      IF(R.LT.0.0) GOTO 6                                              UWDM0037
      A(1)=1.0                                                         UWDM0038
      A(2)=-C4/C2                                                      UWDM0039
      A(3)=-C1*C5/C2                                                   UWDM0040
      A(4)=0.0                                                         UWDM0041
      A(5)=C3/C2*C1**3                                                 UWDM0042
      B(1)=1.0                                                         UWDM0043
      C(1)=1.0                                                         UWDM0044
      Z=HMIN                                                           UWDM0045
C     H**4-C4/C2*H**3-C1/C2*C5*H**2-C1**3*C3/C2=0                      UWDM0046
    3 DO 4 I=2,5                                                       UWDM0047
      B(I)=A(I)+Z*B(I-1)                                               UWDM0048
    4 C(I)=B(I)+Z*C(I-1)                                               UWDM0049
      ZNEW=Z-B(5)/C(4)                                                 UWDM0050
      IF(ABS(ZNEW-Z).LE.0.01*ZNEW) GOTO 5                              UWDM0051
      Z=ZNEW                                                           UWDM0052
      GO TO 3                                                          UWDM0053
    5 H=ZNEW                                                           UWDM0054
      B1=C1/H                                                          UWDM0055
      C4=C4-FRSC                                                       UWDM0056
      R=0.                                                             UWDM0057
      RETURN                                                           UWDM0058
    6 LEN=-1000.0                                                      UWDM0059
      RETURN                                                           UWDM0060
      END                                                              UWDM0061
```

```
      SUBRCUTINE HPCALC(VK,SHPS,PC)
      REAL LEN,KGTRY
      COMMON/CC/SHPM,SHPE,VSUS,VE,RE,DELCF,SFCM,SFCH,MTYPE,JCPT,PCM,PCE
      COMMON/BB/CN,DHV,ENCVCL,DAVG,AREACH,AREAHL,LEN
      COMMON/GG/FRSC,CP,CX,GMMUL,KGTRY,DPTRY,B,H,CWP
      DISPL=DPTRY/1.014
      VOL=DISPL*35.
      BDR=B/H
      RN=VK*LEN*132050.
      CF=.075/(ALOG10(RN)-2.)**2+DELCF
      SLRAT=VK/(SQRT(LEN))
      CV=VOL/(LEN)**3
      IF(BDR.LT.2..OR.BDR.GT.4.) GOTO 1000
      IF(CP.LT..48.OR.CP.GT..7) GOTO 1000
      IF(SLRAT.LT..5.OR.SLRAT.GT.2.) GOTO 1000
      IF(CV.LT..001.OR.CV.GT..006) GOTO 1000
      IF(CV.GT..003.AND.SLRAT.GT.1.3) GOTO 1000
      CALL CRVAL(BDR,CV,CP,SLRAT,CR)
      CT=CF+CR*.001
      S=(1.7*LEN*H+VOL/H)*(.0053*BDR*BDR-.02*BDR+3.*CV+.08*CP+.926)
      A=.00438*1.9905*S
      EHPBH=A*VK**3*CT
      EHPAPP=(1.467-.2*SLRAT)*EHPBH
      EHP=.9*EHPAPP
      IF(SLRAT.LT.1.4.AND.SLRAT.GT..9) EHP=(1.74-.6*SLRAT)*EHPAPP
      IF(SLRAT.LE..9)EHP=1.2*EHPAPP
      SHPS=EHP/PC
      RETURN
 1000 LEN=-1000.
      RETURN
      END
```

```
      SUBROUTINE CRVAL(BTR,CV,CP,VL,CR)                                 CRVL0001
      COMMON /TT/CR1(1152),CR2(972),CR3(216)                            CRVL0002
      I1(J,K,L,M)=(K-1)*384+(J-1)*192+(L-1)*16+M                        CRVL0003
      I2(J,K,L,M)=(K-1)*324+(J-3)*108+(L-1)*9+M                         CRVL0004
      I3(J,K,L,M)=(K-1)*72+(L-1)*6+M                                    CRVL0005
      IF(BTR.GE.3.) K1=2                                                CRVL0006
      IF(BTR.LT.3.) K1=1                                                CRVL0007
      K2=K1+1                                                           CRVL0008
      CP1=.68                                                           CRVL0009
    3 IF(CP-CP1+.0001) 1,2,2                                            CRVL0010
    1 CP1=CP1-.02                                                       CRVL0011
      GOTO 3                                                            CRVL0012
    2 L1=IFIX((CP1-.46)*50.1)                                           CRVL0013
      L2=L1+1                                                           CRVL0014
      CV1=.005                                                          CRVL0015
    4 IF(CV-CV1+.00001) 5,6,6                                           CRVL0016
    5 CV1=CV1-.001                                                      CRVL0017
      GO TO 4                                                           CRVL0018
   13 J1=J1-1                                                           CRVL0019
      CV1=CV1-.001                                                      CRVL0020
      GOTO 14                                                           CRVL0021
    6 J1=IFIX(CV1*1001.)                                                CRVL0022
      IF(J1.EQ.5.AND.VL.GT.1.) GOTO 13                                  CRVL0023
      IF(J1.EQ.2.AND.VL.GT.1.3) GOTO 13                                 CRVL0024
   14 J2=J1+1                                                           CRVL0025
      VL1=1.9                                                           CRVL0026
    7 IF(VL-VL1+.0001) 8,9,9                                            CRVL0027
    8 VL1=VL1-.1                                                        CRVL0028
      GOTO 7                                                            CRVL0029
    9 M1=IFIX((VL1-.4)*10.1)                                            CRVL0030
      M2=M1+1                                                           CRVL0031
      J=J1                                                              CRVL0032
      INDEX=1                                                           CRVL0033
   11 IF(J.GE.3) GOTO10                                                 CRVL0034
      I=I1(J,K1,L1,M1)                                                  CRVL0035
      CRA=CR1(I)                                                        CRVL0036
```

```
      I=I1(J,K1,L1,M2)                                        CRVL0037
      CRB=CR1(I)                                              CRVL0038
      I=I1(J,K1,L2,M1)                                        CRVL0039
      CRC=CR1(I)                                              CRVL0040
      I=I1(J,K1,L2,M2)                                        CRVL0041
      CRD=CR1(I)                                              CRVL0042
      I=I1(J,K2,L1,M1)                                        CRVL0043
      CRE=CR1(I)                                              CRVL0044
      I=I1(J,K2,L1,M2)                                        CRVL0045
      CRF=CR1(I)                                              CRVL0046
      I=I1(J,K2,L2,M1)                                        CRVL0047
      CRG=CR1(I)                                              CRVL0048
      I=I1(J,K2,L2,M2)                                        CRVL0049
      CRH=CR1(I)                                              CRVL0050
      GOTO 50                                                 CRVL0051
   10 IF(J.EQ.6) GO TC 12                                     CRVL0052
      I=I2(J,K1,L1,M1)                                        CRVL0053
      CRA=CR2(I)                                              CRVL0054
      I=I2(J,K1,L1,M2)                                        CRVL0055
      CRB=CR2(I)                                              CRVL0056
      I=I2(J,K1,L2,M1)                                        CRVL0057
      CRC=CR2(I)                                              CRVL0058
      I=I2(J,K1,L2,M2)                                        CRVL0059
      CRD=CR2(I)                                              CRVL0060
      I=I2(J,K2,L1,M1)                                        CRVL0061
      CRE=CR2(I)                                              CRVL0062
      I=I2(J,K2,L1,M2)                                        CRVL0063
      CRF=CR2(I)                                              CRVL0064
      I=I2(J,K2,L2,M1)                                        CRVL0065
      CRG=CR2(I)                                              CRVL0066
      I=I2(J,K2,L2,M2)                                        CRVL0067
      CRH=CR2(I)                                              CRVL0068
      GO TO 50                                                CRVL0069
   12 I=I3(J,K1,L1,M1)                                        CRVL0070
      CRA=CR3(I)                                              CRVL0071
      I=I3(J,K1,L1,M2)                                        CRVL0072
```

```
      CRB=CR3(I)                                                        CRVL0073
      I=I3(J,K1,L2,M1)                                                  CRVL0074
      CRC=CR3(I)                                                        CRVL0075
      I=I3(J,K1,L2,M2)                                                  CRVL0076
      CRD=CR3(I)                                                        CRVL0077
      I=I3(J,K2,L1,M1)                                                  CRVL0078
      CRE=CR3(I)                                                        CRVL0079
      I=I3(J,K2,L1,M2)                                                  CRVL0080
      CRF=CR3(I)                                                        CRVL0081
      I=I3(J,K2,L2,M1)                                                  CRVL0082
      CRG=CR3(I)                                                        CRVL0083
      I=I3(J,K2,L2,M2)                                                  CRVL0084
      CRH=CR3(I)                                                        CRVL0085
   50 V=(VL-VL1)*10.                                                    CRVL0086
      C=(CP-CP1)*50.                                                    CRVL0087
      BTR1=FLOAT((K1-1))*.75+2.25                                       CRVL0088
      B=(BTR-BTR1)/.75                                                  CRVL0089
      C1=(CRB-CRA)*V+CRA                                                CRVL0090
      C2=(CRD-CRC)*V+CRC                                                CRVL0091
      C3=(CRF-CRE)*V+CRE                                                CRVL0092
      C4=(CRH-CRG)*V+CRG                                                CRVL0093
      C5=(C2-C1)*C+C1                                                   CRVL0094
      C6=(C4-C3)*C+C3                                                   CRVL0095
      C7=(C6-C5)*B+C5                                                   CRVL0096
      IF(INDEX.GE.2) GO TO 51                                           CRVL0097
      A=C7                                                              CRVL0098
      J=J2                                                              CRVL0099
      INDEX=2                                                           CRVL0100
      GO TO 11                                                          CRVL0101
   51 D=C7                                                              CRVL0102
      CR=(D-A)*(CV-CV1)*1000.+A                                         CRVL0103
      RETURN                                                            CRVL0104
      END                                                               CRVL0105
```

```
      SUBROUTINE EPLANT
      REAL LEN,NOFF,NCPC,NENL,NAC,KW,KW1
      COMMON/AA/ENDDAY,NOFF,NCPO,NENL
      COMMON/BB/CN,DHV,ENCVOL,DAVG,AREACH,AREAHL,LEN
      COMMON/CC/SHPM,SHPE,VSUS,VE,RE,DELCF,SFCM,SFCH,MTYPE,JOPT,PCM,PCE
      COMMON/DD/ELKW,AVGKW,ELOAD,BLOAD,PALOAD
      IF(JOPT.EQ.2) GOTO 1
      PALOAD=1.
      IF(MTYPE.EQ.2) PALCAD=71.
    1 OALOAD=.0002695*CN
      NAC=NOFF+NCPO+NENL
      HLOAD=.917*NAC
      AVLOAD=15.+.376*NAC*CN/100000.
      KW=ELOAD+BLOAD+PALOAD+OALOAD+HLOAD+AVLOAD
      AVGKW=KW-BLOAD
      KW1=1.25*(1.02*KW+ELOAD)
      ELKW=100.
    2 IF(ELKW.GE.KW1) GOTO 3
      IF(ELKW.LT.240.) GOTO 4
      IF(ELKW.LT.900.) GOTO 5
      ELKW=ELKW+500.
      GOTO 2
    4 ELKW=ELKW+50.
      GOTO 2
    5 ELKW=ELKW+250.
      GOTO 2
    3 RETURN
      END
```

```
      SUBROUTINE MACHLQ
      REAL NOFF,NCPO,NENL,NAC
      COMMON/AA/ENDDAY,NOFF,NCPO,NENL
      COMMON/CC/SHPM,SHPE,VSUS,VE,RE,DELCF,SFCM,SFCH,MTYPE,JOPT,PCM,PCF
      COMMON/DD/ELKW,AVGKW,ELOAD,BLOAD,PALOAD
      COMMON/LL/WTFUEL,WTLO,WTCREW,WTPE,WTPS,WCARGO,WTAMMC,WTAC,WACFUL
      NAC=NOFF+NCPO+NENL
      WTPS=.186*NAC
      IF(JOPT.EQ.2) GOTO 1
      WTLO=.001*SHPM+5.
      IF(MTYPE.EQ.2)WTLC=.0001*SHPM+.001*SHPE+8.5
      IF(MTYPE.EQ.2) GOTO 2
      SFC=.5-.08*SHPE/SHPM
      SHPH=SHPM/2.
      IF(SHPM.GT.7000..AND.SHPE.LT.SHPH) SFC=.5-.16*SHPE/SHPM
      GOTO 3
    2 IF(SHPE.LT.7000.) GOTO 4
      SFC=(1.38-.38*SHPE/50000.)*.5
      IF(SHPM.LE.25000.) SFC=(1.38-.38*SHPE/25000.)*.5
      IF(SHPM.GT.25000..AND. SHPM.LE.35000.)SFC=(1.38-.38*SHPE/35000.)
     1*.5
      GOTO 3
    4 SFC=.42
      GOTO 3
    1 SFC=SFCM+(1.-SHPE/SHPM)*2.*(SFCH-SFCM)
    3 FRMAIN=SFC*SHPE
      FRHOTL=.32*NAC
      FRGEN=.65*AVGKW
      FR=FRMAIN+FRHOTL+FRGEN
      WTFUEL=FR*RE/(1788.*VE)
      RETURN
      END
```

```
      SUBROUTINE MBSIZE (B)                                                 MBSZ0001
      REAL LRD                                                              MBSZ0002
      COMMON/CC/SHPM,SHPE,VSUS,VE,RE,DELCF,SFCM,SFCH,MTYPE,JCPT,PCM,PCF     MBSZ0003
      COMMON/JJ/DHM,XLM,LRD                                                 MBSZ0004
      IF(MTYPE.EQ.2) GOTO 1                                                 MBSZ0005
      XLM=1050./B                                                           MBSZ0006
      IF(SHPM.GT.7000..AND.XLM.LT.56.) XLM=56.                              MBSZ0007
      IF(SHPM.LE.7000..AND.XLM.LT.28.) XLM=28.                              MBSZ0008
      GOTO 2                                                                MBSZ0009
    1 XLM=2300./B                                                           MBSZ0010
      IF(XLM.LT.45.) XLM=45.                                                MBSZ0011
    2 DHM=11.+.00157*SHPM                                                   MBSZ0012
      IF(DHM.GT.22.) DHM=22.                                                MBSZ0013
      RETURN                                                                MBSZ0014
      END                                                                   MBSZ0015
```

```
      SUBROUTINE VOLUME
      REAL LEN,LMB,LRD,NOFF,NCPO,NENL,KGTRY,NAC,LRD1
      COMMON/AA/D,NOFF,NCPO,NENL
      COMMON/BB/CN,DHV,ENCVOL,DAVG,AREACH,AREAHL,LEN
      COMMON/CC/SHPM,SHPE,VSUS,VF,RF,DELCF,SFCM,SFCH,MTYPE,JOPT,PCM,PCF
      COMMON/GG/FRSC,CP,CX,GMMUL,KGTRY,DPTRY,B,H,CWP
      COMMON/II/D0,D10,D20
      COMMON/JJ/DMB,LMB,LRD
      COMMON/LL/WTFUEL,WTLO,WTCREW,WTPE,WTPS,WCARGO,WTAMMO,WTAC,WACFUL
      COMMON/PP/VMB,TANKVL,AVAA,DHAA,ODA,XMFDA,CSDA,OSRDA,OHCA,CPODA,
     1CPOHDA,CBDA,CHDA,CODA,CSTDA,OSDA,WDA,RLCA,CLDA,UTCA,SGCA,ACDA,XICD
     2A,AMDA,PHDA
      KNDEX=0
      NAC=NOFF+NCPO+NENL
      DECKHT=0.
      LRD=0.
      LRD1=0.
   13 CALL SHEER(DMB,F0,F10,F20,D0,D10,D20,LEN,H,DECKHT)
      AREA=LEN/6.*(F0+F20+4.*F10)
      FAVG=AREA/LEN
      DAVG=FAVG+H
      F7=-.018828*(DAVG/H)**2+.18098*DAVG/H+.714599
      HVAW=LEN*B*CWP*FAVG*F7
      HVBW=LEN*B*H*CP*CX
      THV=HVAW+HVBW
      AM=B*H*CX+B*F10
      X=LMB/LEN
      CPM=-.525*X*X+.055*X+.99675
      CPM=CPM+3.2*X*X*(CP-.6)
      VMB=LMB*AM*CPM
      AHVOM=THV-VMB
      Q=(-.9037115+.2139727*D10-1.38263E-2*D10**2+4.008058E-4*D10**3
     1-5.489481E-6*D10**4+2.892153E-8*D10**5)*CP/.58*CX/.814*(1.11*LMB/
     2LEN+.667)
      ATVOM=Q*AHVOM
      VFUEL=WTFUEL*43.
```

```
      VLO=WTLO*39.                                                      VOL 0037
      VFW=.186*NAC*36.                                                  VOL 0038
      VACFUL=WACFUL*44.1                                                VOL 0039
      VREQ=(VFUEL+VLO+VFW+VACFUL)*1.2                                   VOL 0040
      RTAA=0.                                                           VOL 0041
      IF(VREQ.GT.ATVOM) RTAA=(VREQ-ATVOM)/8.5                           VOL 0042
      AAVOM=AHVOM-ATVOM                                                 VOL 0043
      TANKVL=ATVOM+RTAA*8.5                                             VOL 0044
      P=(6.510417E-7*D10**3-7.851484E-5*D10**2+3.438375E-3*D10+.0530399)VOL 0045
     1*(.191*CP+.8893)*(.191*CX+.8445)*(-.105*LMB/LEN+1.0315)           VOL 0046
      AVAA=AAVOM*P-RTAA                                                 VOL 0047
      DHV=.00273*LEN**3                                                 VOL 0048
      DHAA=DHV/8.5                                                      VOL 0049
      CN=(DAVG+LRD/LEN*8.5)*LEN*B                                       VOL 0050
      RDHA=(AREADH+24.+.00225*CN+2.37*LEN)*1.09                         VOL 0051
C     INCLUDES INPUTS, CO CABIN AND PILOT HOUSE WITH ALLOWANCE FOR PASSAGEWAYS VOL 0052
      IF(RDHA.GT.DHAA) GO TO 1000                                       VOL 0053
      TAAA=DHAA+AVAA                                                    VOL 0054
      ODA=2.12*LEN-232.                                                 VOL 0055
      IF(ODA.LT.0.) ODA=0.                                              VOL 0056
      XMFDA=11.9*NAC+500.                                               VOL 0057
      CSDA=4.23*NAC                                                     VOL 0058
      OSRDA=73.*NOFF                                                    VOL 0059
      OHDA=12.*NOFF                                                     VOL 0060
      CPODA=40.*NCPO                                                    VOL 0061
      CPOHDA=8.*NCPO                                                    VOL 0062
      CBDA=22.*NENL                                                     VOL 0063
      CHDA=5.*NENL                                                      VOL 0064
      CODA=2.37*LEN-76.                                                 VOL 0065
      CSTDA=300.+.021*D*NAC                                             VOL 0066
      OSDA=.00719*CN                                                    VOL 0067
      WDA=.00314*CN-157.                                                VOL 0068
      IF(WDA.LT.0.) WDA=0.                                              VOL 0069
      RLDA=100.                                                         VOL 0070
      CLDA=40.                                                          VOL 0071
      UTDA=0.                                                           VOL 0072
```

```
      IF(JOPT.EQ.2) GOTO 8
      UTDA=460.
      IF(MTYPE.EQ.1) UTDA=65.
    8 SGDA=.0014*CN+150.
      ACDA=.00088*CN
      XICDA=.88*LEN+4.
      AMDA=.00485*CN
      PHDA=100.+.00225*CN
      TRAA=1.09*(AREADH+AREAHL+ODA+XMFDA+CSCA+OSRCA+OHDA+CPODA+CPOHDA+
     1CBDA+CHDA+CODA+CSTDA+CSDA+WDA+RLDA+CLDA+UTDA+SGDA+ACDA+XICDA+AMDA+
     2PHDA)
      IF(TRAA.GT.TAAA) GOTO 10
      DHSV=.00151*LEN**3
      DHSAA=DHSV/8.5
      DHAMIN=AMAX1(DHSAA,RDHA)
      TAAA=DHAMIN+AVAA
      IF(TRAA.GT.TAAA) GOTO 11
   12 DHV=DHSV
      DHAA=DHV/8.5
      ENCVOL=DHV+THV
      RETURN
   11 DHAR=TRAA-AVAA
      DHSV=DHAR*8.5
      GOTO 12
   10 RHAA=TRAA-DHAA
      RDAA=RHAA-AVAA
      X1=RDAA/(B*LEN)
      IF(X1.GT..7) GOTO 1
      IF(X1.GT..2) GOTO 2
      LRD=-3.221*X1*X1+2.031*X1-.0184
      GOTO 3
    1 LRD=.463*X1*X1+.446*X1+.22
      GOTO 3
    2 LRD=X1+.059
    3 LRD=LRD*LEN
      DECKHT=8.5
```

```
      IF(ABS(LRD-LRD1).LT..05*LEN) GOTO 15                              VOL 0109
      IF(KNDEX.GT.20) GOTO 1000                                         VOL 0110
      KNDEX=KNDEX+1                                                     VOL 0111
      LRD1=LRD                                                          VOL 0112
      GOTO 13                                                           VOL 0113
   15 C1=.4*LEN                                                         VOL 0114
      C2=.6*LEN                                                         VOL 0115
      AVAA=RHAA                                                         VOL 0116
      IF(LRD.LT.C1.OR.LRD.GT.C2) GOTO 4                                 VOL 0117
      AVAA=AVAA+(C2-LRD)*B                                              VOL 0118
      RDAA=RDAA+(C2-LRD)*B                                              VOL 0119
      LRD=C2                                                            VOL 0120
    4 IF(LRD.GT.LEN) GOTO 1000                                          VOL 0121
      THV=THV+RDAA*8.5                                                  VOL 0122
      ENCVCL=DHV+THV                                                    VOL 0123
      RETURN                                                            VOL 0124
 1000 LEN=-1000.                                                        VOL 0125
      RETURN                                                            VOL 0126
      END                                                               VOL 0127
```

```
      SUBROUTINE SHEER(DMB,F0,F10,F20,D0,D10,D20,LEN,H,DECKHT)
      REAL LEN
      D10=.0025*LEN+DMB
      IF(D10.LT.LEN/16.) D10= LEN/16.
      F0=1.011827*(100.*H/LEN)-.000636215*LEN+2.780649
      F0=LEN*F0/100.
      F0=F0-DECKHT
      D0=F0+H
      F20=.01*LEN*(2.125+.00125*LEN)
      D20=F20+H
    7 S0=D0-D10
      R0=S0/LEN
      IF(R0.LT..01) GOTO 1
      IF(R0.GT..03) GOTO 2
    6 S20=D20-D10
      R20=S20/LEN
      IF(R20.LT..001) GOTO 3
      IF(R20.GT..0075) GOTO 4
      GOTO 5
    1 S0=.01*LEN
      D0=S0+D10
      GOTO 6
    2 S0=.03*LEN
      D10=D0-S0
      GOTO 6
    3 S20=.001*LEN
      D20=D10+S20
      GOTO 5
    4 S20=.0075*LEN
      D10=D20-S20
      GOTO 7
    5 F0=D0-H
      F20=D20-H
      F10=D10-H
      RETURN
      END
```

```
      SUBROUTINE WEIGHT                                                 WGHT0001
      REAL LEN,NOFF,NCPO,NENL,NAC                                       WGHT0002
      COMMON/AA/D,NOFF,NCPO,NENL                                        WGHT0003
      COMMON/BB/CN,DHV,ENCVOL,DAVG,AREADH,AREAHL,LEN                    WGHT0004
      COMMON/CC/SHPM,SHPE,VSUS,VE,RF,DELCF,SFCM,SFCH,MTYPE,JCPT,PCM,PCE WGHT0005
      COMMON/DD/ELKW,AVGKW,ELOAD,BLOAD,PALOAD                           WGHT0006
      COMMON/LL/WTFUEL,WTLO,WTCREW,WTPE,WTPS,WCARGO,WTAMMO,WTAC,WACFUL  WGHT0007
      COMMON/VV/WT1M,WT111,WT112,WT113,WT2M,WT203,WT30C,WT301,WT3R,WT6I,WGHT0008
     1WT6II,WT6III,WT6IV                                                WGHT0009
      COMMON/WW/WTG1,WTG2,WTG3,WTG4,WTG5,WTG6,WTG7,WLSHIP,WFULLD,DBMAR  WGHT0010
      WT1M=.0016915*CN                                                  WGHT0011
      WT111=10.+.0013751*DHV                                            WGHT0012
      WT203=.56*LEN*(.0000159*SHPM+.0765)                               WGHT0013
      IF(JOPT.EQ.2) GOTO 1                                              WGHT0014
      IF(MTYPE.EQ.1) GOTO 2                                             WGHT0015
      WT2M=256.3-.0041*(7000.-SHPE)                                     WGHT0016
      IF(SHPE.GT.7000.) WT2M=256.3                                      WGHT0017
      GOTO 3                                                            WGHT0018
    2 WT2M=.0184615*SHPM+1.0385                                         WGHT0019
      GOTO 3                                                            WGHT0020
    1 WT2M=WTG2-WT203                                                   WGHT0021
    3 WT112=.1121*WT2M                                                  WGHT0022
      WT300=.054*ELKW                                                   WGHT0023
      IF(ELKW.GE.500.) WT300=41.54+.01068*ELKW                          WGHT0024
      IF(ELKW.GT.800.) WT300=5.38+.06748*ELKW                           WGHT0025
      WT301=.01335*ELKW                                                 WGHT0026
      WT3R=0.109*LEN                                                    WGHT0027
      VOL=ENCVOL/100000.                                                WGHT0028
      WTG5=-2.884*VOL*VOL+81.82*VOL                                     WGHT0029
      WT6I=.001411*ENCVOL                                               WGHT0030
      NAC=NOFF+NCPO+NENL                                                WGHT0031
      WT6II=.001158*NAC*NAC+.5819*NAC                                   WGHT0032
      Q=NAC/15.+1.                                                      WGHT0033
      RAFTS=AINT(Q)                                                     WGHT0034
      BOATWT=1.4                                                        WGHT0035
      IF(NAC.GT.25.) BOATWT=5.                                          WGHT0036
```

```
      IF(NAC.GT.50.) BOATWT=10.1                                        WGHT0037
      WT6III=BOATWT+.2*RAFTS+.002*NAC                                   WGHT0038
      WT6IV=.00206*NAC*NAC+.20265*NAC                                   WGHT0039
      WTG6=WT6I+WT6II+WT6III+WT6IV                                      WGHT0040
      WTG3=WT300+WT301+WT302                                            WGHT0041
      WTG2=WT2M+WT203                                                   WGHT0042
      WTFDS=WTG3+WTG4+WTG5+WTG7                                         WGHT0043
      WT113=.0615*WTFDS                                                 WGHT0044
      WTG1=WT1M+WT111+WT112+WT113                                       WGHT0045
      WLSHIP=(WTG1+WTG2+WTG3+WTG4+WTG5+WTG6+WTG7)*DBMAR                 WGHT0046
      WTCREW=.0737*NAC                                                  WGHT0047
      WTPE=.105*NOFF+.0737*NCPO+.029*NENL                               WGHT0048
      WTPS=(.0222+.00202*D)*NAC+.00135*D*NAC+.186*NAC                   WGHT0049
      WFULLD=WLSHIP+WTCREW+WTPE+WTPS+WTLO+WTFUEL+WCARGO+WTAMMO+WTAC+    WGHT0050
     1WACFUL                                                            WGHT0051
      RETURN                                                            WGHT0052
      END                                                               WGHT0053
```

```
      SUBROUTINE VCG(CFULD)
      REAL LEN,LRD
      COMMON/AA/D,DFF,CPD,ENL
      COMMCN/BB/CN,DHV,ENCVOL,DAVG,AREACH,AREAHL,LEN
      COMMCN/EE/GR4WT(20),GR4CG(20),GR7WT(20),GR7CG(20),AMOWT(20),
     1AMOCG(20),ACWT(20),ACCG(20),CARGOW(20),CARGOC(20)
      COMMCN/HH/CGFUEL,CGLO,CGCREW,CGPE,CGPS,CCARGO,CGAMMO,CGAC,CACFUL
      COMMON/OO/CGG1,CGG2,CGG3,CGG4,CGG5,CGG6,CGG7,CLSHIP,CFULLD
      COMMON/LL/WTFUEL,WTLO,WTCREW,WTPE,WTPS,WCARGO,WTAMMO,WTAC,WACFUL
      COMMON/WW/WTG1,WTG2,WTG3,WTG4,WTG5,WTG6,WTG7,WLSHIP,WFULLD,DBMAR
      COMMON/II/DO,D10MN,D20
      COMMON/JJ/DHM,XLM,LRD
      COMMON/VV/WT1M,WT111,WT112,WT113,WT2M,WT203,WT30C,WT301,WT3R,WT6I,
     1WT6II,WT6III,WT6IV
      COMMON/FF/TITLE(5,40),HEAD(20),NOARM,NOELT
      CG1M=.55*DAVG
      HLEN=LEN/2.
      D10=D1CMN
      IF(LRD.GE.HLEN) D10=D10MN+8.5
      CG111=1.4*D10
      CG112=.2*D10
      CG2M=.54*D1CMN
      CG203=.16*D10
      CG300=.7*D10
      CG301=.8*D10
      CG3R=D10
      CGG5=.71*D10
      CG6I=.75*D10
      CG6II=D10
      CG6III=1.6*D10MN
      CG6IV=.84*D10
      G4MOM=0.
      DO1 I=1,NOELT
    1 G4MOM=G4MOM+GR4WT(I)*GR4CG(I)
      CGG4=0.
      IF(G4MOM.GT.1.) CGG4=G4MOM/WTG4*D10MN
```

```
      ACMOM=0.                                                          VCG 0037
      G7MOM=0.                                                          VCG 0038
      AMOMOM=0.                                                         VCG 0039
      CGOMOM=0.                                                         VCG 0040
      DO 2 I=1,NOARM                                                    VCG 0041
      ACMOM=ACMOM+ACWT(I)*ACCG(I)                                       VCG 0042
      G7MOM=G7MOM+GR7WT(I)*GR7CG(I)                                     VCG 0043
      AMOMOM=AMOMOM+AMOWT(I)*AMOCG(I)                                   VCG 0044
    2 CGOMOM=CGOMOM+CARGOW(I)*CARGOC(I)                                 VCG 0045
      CGG7=0.                                                           VCG 0046
      IF(G7MOM.GT.1.) CGG7=G7MOM*D1OMN/WTG7                             VCG 0047
      CCARGO=0.                                                         VCG 0048
      IF(CGOMOM.GT.1.) CCARGO=CGOMOM/WCARGO*D1OMN                       VCG 0049
      CGAC=0.                                                           VCG 0050
      IF(ACMOM.GT.1.) CGAC=ACMOM*D1OMN/WTAC                             VCG 0051
      CGAMMO=0.                                                         VCG 0052
      IF(AMOMOM.GT.1.) CGAMMO=AMOMOM*D1OMN/WTAMMO                       VCG 0053
      CACFL=CACFUL*D1OMN                                                VCG 0054
      CGG3=(CG300*WT300+CG301*WT301+CG3R*WT3R)/WTG3                     VCG 0055
      CGG6=(CG6I*WT6I+CG6II*WT6II+CG6III*WT6III+CG6IV*WT6IV)/WTG6       VCG 0056
      CGG2=(CG2M*WT2M+CG203*WT203)/WTG2                                 VCG 0057
      CG113=.87*(CGG3*WTG3+CGG4*WTG4+CGG5*WTG5+CGG7*WTG7)/(WTG3+WTG4+   VCG 0058
     1WTG5+WTG7)                                                        VCG 0059
      CGG1=(CG1M*WT1M+CG111*WT111+CG112*WT112+CG113*WT113)/WTG1         VCG 0060
      CLSHIP=(CGG1*WTG1+CGG2*WTG2+CGG3*WTG3+CGG4*WTG4+CGG5*WTG5+CGG6*   VCG 0061
     1WTG6+CGG7*WTG7)*DBMAR/WLSHIP                                      VCG 0062
      CGFUEL=.3*D10                                                     VCG 0063
      CGLO=.13*D1OMN                                                    VCG 0064
      CGCREW=.97*D1OMN                                                  VCG 0065
      CGPE=CGCREW                                                       VCG 0066
      CGPW=.26*D10                                                      VCG 0067
      CGGS=.85*D1OMN                                                    VCG 0068
      CGPV=.55*D10                                                      VCG 0069
      CGPS=((.0222+.00202*D)*CGPV+.00135*D*CGGS+.186*CGPW)/(.2082+.00337 VCG 0070
     1*D)                                                               VCG 0071
      XLDMOM=(CGFUEL*WTFUEL+CGLO*WTLO+CGCREW*WTCREW+CGPE*WTPE+CGPS*WTPS VCG 0072
```

```
     1+CCARGO*WCARGO+CGAMMO*WTAMMO+CGAC*WTAC+CACFL *WACFUL)             VCG 0073
      CFULLD=(CLSHIP*WLSHIP+XLDMCM)/WFULLD                              VCG 0074
      CFULD=CFULLD                                                      VCG 0075
      RETURN                                                            VCG 0076
      END                                                               VCG 0077
```

```
      SUBROUTINE COST(LEN)                                               COST0001
      REAL MCST                                                          COST0002
      REAL LEN,LABCST,MATCST,LOA                                         COST0003
      COMMON/CC/SHPM,SHPE,VSUS,VE,PE,DELCF,SFCM,SFCH,MTYPE,JCPT,PCM,PCF  COST0004
      COMMON/MM/CSTG1,CSTG2,CSTG3,CSTG4,CSTG5,CSTG6,CSTG7,DCST,CCST,MCST COST0005
      COMMON/NN/ DOLHR,G1INC,G2IND,G3INC,G5IND,G6IND,TOTCST              COST0006
      COMMON/WW/WTG1,WTG2,WTG3,WTG4,WTG5,WTG6,WTG7,WLSHIP,WFULLD,DBMAR   COST0007
      W1=WTG1*DBMAR                                                      COST0008
      W2=WTG2*DBMAR                                                      COST0009
      W3=WTG3*DBMAR                                                      COST0010
      W4=WTG4*DBMAR                                                      COST0011
      W5=WTG5*DBMAR                                                      COST0012
      W6=WTG6*DBMAR                                                      COST0013
      W7=WTG7*DBMAR                                                      COST0014
      G1MH=10.**(ALOG10(W1)*.75217+2.97276)                              COST0015
      G2MH=10.**(ALOG10(W2)*1.0273+2.3437)                               COST0016
      G3MH=10.**(ALOG10(W3)*1.07776+2.62981)                             COST0017
      G4MH=10.**(ALOG10(W4)*1.07776+2.62981)                             COST0018
      G5MH=10.**(ALOG10(W5)*.763428+3.2366)                              COST0019
      G6MH=10.**(ALOG10(W6)*.9742+2.74181)                               COST0020
      G7MH=10.**(ALOG10(W7)*.75217+2.97276)                              COST0021
      G1MC=10.**(ALOG10(W1)*.954243+2.790484)                            COST0022
      G2MC=CSTG2                                                         COST0023
      IF(JOPT.EQ.2) GOTO 1                                               COST0024
      G2MC=10.**(ALOG10(W2)*1.018885+3.634328)                           COST0025
      IF(MTYPE.EQ.2) G2MC=G2MC+1500000.                                  COST0026
    1 G3MC=10.**(ALOG10(W3)*1.072551+3.667812)                           COST0027
      G4MC=CSTG4                                                         COST0028
      G5MC=10.**(ALOG10(W5)*.870906+3.974192)                            COST0029
      G6MC=10.**(ALOG10(W6)*1.068265+3.603833)                           COST0030
      G7MC=CSTG7                                                         COST0031
      G1LC=G1MH*DOLHR*1.98                                               COST0032
      G2LC=G2MH*DOLHR*1.98                                               COST0033
      G3LC=G3MH*DOLHR*1.98                                               COST0034
      G4LC=G4MH*DOLHR*1.98                                               COST0035
      G5LC=G5MH*DOLHR*1.98                                               COST0036
```

```
      G6LC=G6MH*DOLHR*1.98                                              COST0037
      G7LC=G7MH*DOLHR*1.98                                              COST0038
      G1MC=G1MC*G1IND*1.1                                               COST0039
      IF(JOPT.EQ.2) GOTO 2                                              COST0040
      G2MC=G2MC*G2IND                                                   COST0041
    2 G3MC=G3MC*G3IND*1.1                                               COST0042
      G5MC=G5MC*G5IND*1.1                                               COST0043
      G6MC=G6MC*G6IND*1.1                                               COST0044
      G2MC=G2MC*1.1                                                     COST0045
      G4MC=G4MC*1.1                                                     COST0046
      G7MC=G7MC*1.1                                                     COST0047
      LABCST=G1LC+G2LC+G3LC+G4LC+G5LC+G6LC+G7LC                         COST0048
      MATCST=G1MC+G2MC+G3MC+G4MC+G5MC+G6MC+G7MC                         COST0049
      LOA=1.08*LEN                                                      COST0050
      FACTOR=(.114*LCA-1.6)/100.                                        COST0051
      DLC=FACTOR*LABCST                                                 COST0052
      FACTOR=(-.01*LOA+7.5)/100.                                        COST0053
      DMC=FACTOR*MATCST                                                 COST0054
      FACTOR=(.014*LOA+7.)/100.                                         COST0055
      CLC=FACTOR*LABCST                                                 COST0056
      FACTOR=(-.015*LOA+6.5)/100.                                       COST0057
      CMC=FACTOR*MATCST                                                 COST0058
      TOTCST=LABCST+MATCST+DLC+DMC+CLC+CMC                              COST0059
      ORICST=.02*TOTCST                                                 COST0060
      SPARES=(.09*G2MC+.08*G3MC+.25*G4MC+.1*G5MC)/1.1                   COST0061
      RETRO=.04*TOTCST                                                  COST0062
      ADMIN=.035*TOTCST                                                 COST0063
      CSTG1=G1LC+G1MC                                                   COST0064
      CSTG2=G2LC+G2MC                                                   COST0065
      CSTG3=G3LC+G3MC                                                   COST0066
      CSTG4=G4LC+G4MC                                                   COST0067
      CSTG5=G5LC+G5MC                                                   COST0068
      CSTG6=G6LC+G6MC                                                   COST0069
      CSTG7=G7LC+G7MC                                                   COST0070
      DCST=DLC+DMC                                                      COST0071
      CCST=CLC+CMC                                                      COST0072
```

```
      MCST=ORICST+SPARES+RETRO+ADMIN                                    CCST0073
      TOTCST=TOTCST+MCST                                                COSTC074
      RETURN                                                            COST0075
      END                                                               COST0076
```

```
      SUBROUTINE SEASPD(AVSP)
      REAL LEN,KGTRY,KY,IY,JY,IYY
      COMMON/BB/ CN,DHV,ENCVOL,DAVG,AREADH,AREAHL,LEN
      COMMON/CC/SHPM,SHPE,VSUS,VE,RE,DELCF,SFCM,SFCH,MTYPE,JOPT,PCM,PCE
      COMMON/GG/FRSC,CP,CX,GMMUL,KGTRY,DPTRY,B,H,CWP
      KY=.24
      G=32.155
      R=1.9905
      PI=3.14159
      IY=(KY*LEN)**2*2240.*DPTRY/G
      CIL=.1421C526*CWP-.063568
      JY=CIL*B*LEN**3
      C=H
      B1=B/2.
      A=LEN/2.
      BCC=B1/C+1.19-(1.64-.86666697E-1*A/B1+.625E-2*(A/B1)**2-.20833346E
     1-3*(A/B1)**3)
      YYK1=.66302837E-1+.5773045*BCC+.31592344*BCC**2-.15287906*BCC**3
     1+.028399747*BCC**4
      IF(CX-.814)1,2,3
    3 CXP=(CX-.814)*.81395
      CXH=(CX-.814)*.60465
      GOTO 4
    2 CXP=0.
      CXH=0.
      GOTC 4
    1 CXP=0.
      CXH=(CX-.814)*.27193
    4 FKYY=.6051
      CPP=(CP-.58)*2.76666
      CSP=FKYY+CPP+CXP
      IYY=YYK1*CSP/120.*PI*R*LEN*B*H*(LEN*LEN+4.*H*H)
      TP=2.*PI*((IY+IYY)/(G*R*JY))**.5
      ZK1=1.9+(B1/C-2.)/1.05
      FKZ=.599
      CPH=(CP-.58)*1.41666
```

```
      CSH=FKZ+CPH+CXH
      SM=2240.*DPTRY/G
      AWP=CWP*LEN*B
      ZM=CSH*ZK1*PI*R*LEN*B*H/6.
      TH=6.28318*SQRT((SM+ZM)/(G*R*AWP))
      TPL=TP/(SQRT(LEN))
      THL=TH/(SQRT(LEN))
      T=TPL
      IF(THL.GT.TPL) T=THL
      VLR=(.9025/T-SQRT(.95*G/(2.*PI)))/1.6878
      WAVEH=.0256465*LEN
      W=DPTRY/(100.*(.01*LEN)**3)
      WW=(11.*W*W-8.25281*W+3.86439)/6000.
      VRT=16.*H/LEN+.60293*W-.15617+WW*LEN
      VLR=VRT*VLR
      SPEED=VLR*SQRT(LEN)
      IF(SPEED.LT.VSUS) GOTO 6
      PER1=100.
      GOTO 5
    6 IF(WAVEH.LT.8.) GOTO 7
      IF(WAVEH.LT.13.) GOTO 8
      PER1=-40.49996+14.949994*WAVEH-.54333305*WAVEH**2+.66666623E-2*
     1WAVEH**3
      GOTO 5
    8 PER1=-126.00002+21.933338*WAVEH-.25625043*WAVEH**2-.017708321*
     1WAVEH**3
      GOTO 5
    7 PER1=-.89785317E-7+.14285863*WAVEH-.13333482*WAVEH**2+.037500399*
     1WAVEH**3+.29761609E-2*WAVEH**4
    5 PER2=(100.-PER1)/2.
      PER=100.-PER2
      AVSP=(PER*VSUS+PER2*SPEED)/100.
      RETURN
      END
```

```
      SUBROUTINE OUTPLT(AVSP,EXCKG,I1)
      REAL LEN,NOFF,NCPO,NENL,KGTRY
      REAL LRD
      REAL MCST
      COMMON/AA/D,NOFF,NCPO,NENL
      COMMON/BB/CN,DHV,ENCVOL,DAVG,AREADH,AREAHL,LEN
      COMMON/CC/SHPM,SHPE,VSUS,VE,RE,DELCF,SFCM,SFCH,MTYPE,JCPT,PCM,PCE
      COMMON/DD/ELKW,AVGKW,ELOAD,BLOAD,PALOAD
      COMMON/EE/GR4WT(20),GR4CG(20),GR7WT(20),GR7CG(20),AMOWT(20),AMOCG
     1(20),ACWT(20),ACCG(20),CARGOW(20),CARGOC(20)
      COMMON/FF/ TITLE(5,40),HEAD(20),NCARM,NCELT
      COMMON/GG/FRSC,CP,CX,GMMUL,KGTRY,DPTRY,B,H,CWP
      COMMON/HH/CGFUEL,CGLO,CGCREW,CGPE,CGPS,CCARGO,CGAMMO,CGAC,CACFUL
      COMMON/II/D0,D10,D20
      COMMON/JJ/DHM,XLM,LRD
      COMMON/KK/ELLD(20),DHAR(20),HLAR(20),ELD(20),DHA(20),HLA(20),
     1GR7CST(20),GR4CST(20)
      COMMON/LL/WTFUEL,WTLO,WTCREW,WTPE,WTPS,WCARGO,WTAMMO,WTAC,WACFUL
      COMMON/MM/CSTG1,CSTG2,CSTG3,CSTG4,CSTG5,CSTG6,CSTG7,DCST,CCST,MCST
      COMMON/NN/ DOLHR,G1IND,G2IND,G3IND,G5IND,G6IND,TOTCST
      COMMON/OO/CGG1,CGG2,CGG3,CGG4,CGG5,CGG6,CGG7,CLSHIP,CFULLD
      COMMON/PP/VMB,TANKVL,AVAA,DHAA,ODA,XMFDA,CSDA,OSRDA,OHDA,CPODA,
     1CPOHDA,CBDA,CHDA,CODA,CSTDA,OSDA,WDA,RLDA,CLDA,UTDA,SGDA,ACDA,XICD
     2A,AMDA,PHDA
      COMMON/WW/WTG1,WTG2,WTG3,WTG4,WTG5,WTG6,WTG7,WLSHIP,WFULLD,DBMAR
      WRITE(5,100) HEAD
  100 FORMAT('1',20A4/)
      WRITE(5,101)
  101 FORMAT(T30,'*****INPUT DATA*****'//' ARMAMENT, AIRCRAFT AND CARGO
     1INPUTS'//,T9,'ITEM',T26,'CARGO   CARGO  GROUP 7 GROUP 7  AMMO',T66
     2,'AMMO  AIRCRAFTAIRCRAFT  ELECT  AREA IN AREA IN GROUP 7'/,T25,
     3'WEIGHT    VCG   WEIGHT    VCG   WEIGHT   VCG    WEIGHT   VCG',T90
     4,'LOAD  DECKHSE   HULL    COST'/)
      WRITE(5,102)((TITLE(J,I),J=1,5),CARGOW(I),CARGOC(I),GR7WT(I),GR7CG
     1(I),AMOWT(I),AMOCG(I),ACWT(I),ACCG(I),ELLD(I),DHAR(I),HLAR(I),
     2GR7CST(I),I=1,NCARM)
```

```
102 FORMAT(' ',5A4,F8.1,F8.3,F8.1,F8.3,F8.1,F8.3,F8.1,F8.3,F8.3,F8.0,      OUTP0037
   1F8.0,F8.0)                                                             OUTP0038
    WRITE(5,103)                                                           OUTP0039
103 FORMAT(/' ELECTRONICS INPUT'//T9,'ITEM',T24,'GROUP 4 GROUP 4',T41,     OUTP0040
   1'ELECT  AREA IN AREA IN GROUP 4'/,T24,'WEIGHT   VCG     LOAD',T48,    OUTP0041
   2'DECKHSE  HULL    COST'/)                                              OUTP0042
    WRITE(5,104)((TITLE(J,I+20),J=1,5),GR4WT(I),GR4CG(I),ELC(I),DHA(I)    OUTP0043
   1,HLA(I),GR4CST(I),I=1,NDELT)                                           OUTP0044
104 FORMAT(' ',5A4,F8.1,2F8.3,3F8.0)                                       OUTP0045
    WRITE(5,105)                                                           OUTP0046
105 FORMAT(/' MANNING INPUT'/)                                             OUTP0047
    WRITE(5,106) NOFF,NCPO,NENL                                            OUTP0048
106 FORMAT('  NO. OF OFFICERS = ',F5.0,5X,'NO. OF CPOS = ',F5.0,5X,        OUTP0049
   1'NO. OF ENLISTED MEN = ',F5.0,/)                                       OUTP0050
    WRITE(5,121)                                                           OUTP0051
121 FORMAT(' COST INDICES INPUT'/)                                         OUTP0052
    WRITE(5,119) DOLHR,G1IND,G2IND,G3IND,G5IND,G6IND                       OUTP0053
119 FORMAT('  LABOR RATE = ',F5.2,' DOLLARS/HR'/'  GROUP 1 INDEX = ',      OUTP0054
   1F5.2/'  GROUP 2 INDEX = ',F5.2/'  GROUP 3 INDEX = ',F5.2/'  GROUP     OUTP0055
   25 INDEX = ',F5.2/'  GROUP 6 INDEX = ',F5.2/)                           OUTP0056
    WRITE(5,120)                                                           OUTP0057
120 FORMAT('      INDICES INCLUDE EFFECTS OF INFLATION AND SPECIAL MAT    OUTP0058
   1ERIAL COSTS'/)                                                         OUTP0059
    WRITE(5,107)                                                           OUTP0060
107 FORMAT(' MILITARY MISSION CONSUMABLES INPUT'/)                         OUTP0061
    WRITE(5,108) D,WACFUL,CACFUL                                           OUTP0062
108 FORMAT('  NO. ENDURANCE DAYS = ',F5.0,'  WEIGHT AIRCRAFT FUEL = ',     OUTP0063
   1F7.1,'  VCG AIRCRAFT FUEL = ',F8.3)                                    OUTP0064
    DBMAR=DBMAR-1.                                                         OUTP0065
    WRITE(5,109)                                                           OUTP0066
109 FORMAT(/,' VEHICLE PERFORMANCE INPUT')                                 OUTP0067
    IF(JOPT.EQ.2) GOTO 2                                                   OUTP0068
    WRITE(5,110) VSUS,VE,RE,PCE,PCM                                        OUTP0069
110 FORMAT(/'  MAX SUSTAINED SHP COMPUTED'/,' SUSTAINED SPEED = ',F8.2    OUTP0070
   1,' KTS'/,' ENDURANCE SPEED = ',F8.2,' KTS'/,' ENDURANCE RANGE = ',    OUTP0071
   2F8.0,' MILES'/,' PROP COEF ENDURANCE = ',F5.3,/,' PROP COEF MAXIMU    OUTP0072
```

```
 3M = ',F5.3,/)                                                           OUTP0073
      GOTO 3                                                              OUTP0074
    2 WRITE(5,111) SHPM,DHM,XLM,WTG2,SFCM,SFCH,VE,RE,PALCAD,PCE,PCM,      OUTP0075
     1CSTG2,WTLC                                                          OUTP0076
  111 FORMAT('  MAX SUSTAINED SPEED COMPUTED'/,' MAX SUSTAINED SHP = ',   OUTP0077
     1F8.0,/,' MIN DECKHEIGHT FOR MACHINERY = ',F5.2,' FT'/,' MIN LENGTH  OUTP0078
     2 OF MACHINERY BOX = ',F6.2,' FT'/,' GROUP 2 WEIGHT = ',F8.1,' TONS  OUTP0079
     3'/,' SFC MAX POWER = ',F5.3,' LBS/SHP-HR'/,' SFC HALF POWER = ',    OUTP0080
     4F5.3,' LBS/SHP-HR'/,' ENDURANCE SPEED = ',F8.2,' KTS'/,' ENDURANCE  OUTP0081
     5 RANGE = ',F8.0,' MILES'/,' PROP AUX ELECT LOAD = ',F8.3,' KW'/,    OUTP0082
     6' PROP COEF ENDURANCE = ',F5.3,/' PROP COEF MAXIMUM = ',F5.3,/,     OUTP0083
     7' GROUP 2 COST = ',F9.0,' DOLLARS'/,' WEIGHT OF LUB OIL = ',F8.1,   OUTP0084
     8' TONS'/)                                                           OUTP0085
    3 WRITE(5,112) MTYPE,FRSC,GMMUL,DBMAR,DELCF,LEN,CP,CX                 OUTP0086
  112 FORMAT('  OPTIONS'//,' MTYPE = ',I2,/,' FREE SURFACE CORRECTION =   OUTP0087
     1',F5.2,' FT',/,' GM MULTIPLIER = ',F5.3,/,' DESIGN AND BUILDERS MA  OUTP0088
     2RGIN = ',F5.3,/,' DELTA CF = ',F8.5,/,' LENGTH = ',F5.1, ' FT',/    OUTP0089
     3,' CP = ',F5.3,/,' CX = ',F5.3,/)                                   OUTP0090
      IF(I1.EQ.1) RETURN                                                  OUTP0091
      DAVG=DAVG+LRD/LEN*8.5                                               OUTP0092
      WRITE(5,113)                                                        OUTP0093
  113 FORMAT(//,T33,'*****OUTPUT*****'//,'  LENGTH  BEAM   DRAFT  DO      OUTP0094
     1D10   D20   DAVG  LNTH RD  CP    CX  DISPLACEMENT  SHPMAX    VSUS   OUTP0095
     2  SHPEND'/)                                                         OUTP0096
      WRITE(5,114)LEN,B,H,DO,D10,D20,DAVG,LRD,CP,CX,DPTRY,SHPM,VSUS,SHPE  OUTP0097
  114 FORMAT(' ',F6.1,F8.2,F7.2,4F6.2,F9.1,2F6.3,F9.1,F11.0,F8.2,F9.0)    OUTP0098
      WRITE(5,160) AVSP                                                   OUTP0099
  160 FORMAT(/,' AVERAGE SPEED IN SEAWAY IS ',F5.2,' KNOTS'/)             OUTP0100
      VOL=ENCVOL-DHV                                                      OUTP0101
      WRITE(5,115) ELKW                                                   OUTP0102
  115 FORMAT(/,' ELECTRIC PLANT CAPACITY/GEN = ',F8.0,' KW'/)             OUTP0103
      FFF=1.+DBMAR                                                        OUTP0104
      R1=WTG1/WFULLD*FFF                                                  OUTP0105
      R2=WTG1/WLSHIP*FFF                                                  OUTP0106
      R3=WTG2/WFULLD*FFF                                                  OUTP0107
      R4=WTG2/WLSHIP*FFF                                                  OUTP0108
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      R5=WTG3/WFULLD*FFF                                                OUTP0109
      R6=WTG3/WLSHIP*FFF                                                OUTP0110
      R7=WTG4/WFULLD*FFF                                                OUTP0111
      R8=WTG4/WLSHIP*FFF                                                OUTP0112
      R9=WTG5/WFULLD*FFF                                                OUTP0113
      R10=WTG5/WLSHIP*FFF                                               OUTP0114
      R11=WTG6/WFULLD*FFF                                               OUTP0115
      R12=WTG6/WLSHIP*FFF                                               OUTP0116
      R13=WTG7/WFULLD*FFF                                               OUTP0117
      R14=WTG7/WLSHIP*FFF                                               OUTP0118
      R15=WLSHIP/WFULLD                                                 OUTP0119
      R16=1.                                                            OUTP0120
      WRITE(5,116)WTG1,CGG1,R1,R2,CSTG1,WTG2,CGG2,R3,R4,CSTG2,WTG3,CGG3,OUTP0121
     1R5,R6,CSTG3,WTG4,CGG4,R7,R8,CSTG4,WTG5,CGG5,R9,R10,CSTG5,WTG6,CGG6OUTP0122
     2,R11,R12,CSTG6,WTG7,CGG7,R13,R14,CSTG7,WLSHIP,CLSHIP,R15,R16,TOTCSOUTP0123
     3T                                                                 OUTP0124
  116 FORMAT(/' ',8X,'WEIGHTS      VCG      WT/WFULLD   WT/WLSHIP     COOUTP0125
     1ST'//' WTG1',F10.1,3F12.3,F12.0/' WTG2',F10.1,3F12.3,F12.0/' WTG3'OUTP0126
     2,F10.1,3F12.3,F12.0/' WTG4',F10.1,3F12.3,F12.0/' WTG5',F10.1,3F12.OUTP0127
     33,F12.0/' WTG6',F10.1,3F12.3,F12.0/' WTG7',F10.1,3F12.3,F12.0//,  OUTP0128
     4' WLSHIP',F8.1,3F12.3,F12.0,' = TOTAL COST'/)                     OUTP0129
      R1=WTFUEL/WFULLD                                                  OUTP0130
      R2=WTLO/WFULLD                                                    OUTP0131
      R3=WTCREW/WFULLD                                                  OUTP0132
      R4=WTPE/WFULLD                                                    OUTP0133
      R5=WTPS/WFULLD                                                    OUTP0134
      R6=WCARGO/WFULLD                                                  OUTP0135
      R7=WTAMMO/WFULLD                                                  OUTP0136
      R8=WTAC/WFULLD                                                    OUTP0137
      R9=WACFUL/WFULLD                                                  OUTP0138
      CACFL=CACFUL*D10                                                  OUTP0139
      WRITE(5,117)WTFUEL,CGFUEL,R1,WTLO,CGLO,R2,WTCREW,CGCREW,R3,WTPE,  OUTP0140
     1CGPE,R4,WTPS,CGPS,R5,WCARGO,CCARGO,R6,WTAMMO,CGAMMO,R7,WTAC,CGAC, OUTP0141
     2R8,WACFUL,CACFL,R9,WFULLD,CFULLD                                  OUTP0142
  117 FORMAT(' FUEL',F10.1,2F12.3/' LUB OIL',F7.1,2F12.3/' CREW',F10.1, OUTP0143
     12F12.3/' PER EFF',F7.1,2F12.3/' PER STR',F7.1,2F12.3/' CARGO',F9.1OUTP0144
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   2,2F12.3/' AMMO',F10.1,2F12.3/' AIR CFT',F7.1,2F12.3/' A/C FUEL',
   3F6.1,2F12.3//' WFLLLD',F9.1,F12.3//)
    WRITE(5,122) EXCKG
122 FORMAT(' A MARGIN ON KG OF ',F6.3,' FT EXISTS ABOVE THE FULL LOAD
   1KG VALUE GIVEN '//)
    WRITE(5,118) DCST,CCST,MCST
118 FORMAT(' NOTE   D&R MARGIN INCLUDED IN WLSHIP AND COST ESTIMATES B
   1UT NOT IN INDIVIDUAL WEIGHT GROUPS'/'         OVERHEAD AND PROFIT A
   2RE INCLUDED IN INDIVIDUAL WEIGHT GROUP COSTS'/'         TOTAL COST
   3INCLUDES A DESIGN COST OF',F12.0,' DOLLARS'/' ',19X,'A CONST SERVI
   4CES COST OF',F12.0,' DOLLARS'/' ',19X,'AND A MISC. ITEM COST OF',
   5F12.0,' DOLLARS'/'         MISC.ITEM COST INCLUDES ORI OUTFIT, SPAR
   6ES, RETROFIT COSTS, AND ADMINISTRATIVE COSTS(RIO)'/)
    WRITE(5,123) VOL,DHV
123 FORMAT(/,' VOLUME OF HULL = ',F10.0,' CU FT'/,' VOLUME OF DECKHOUS
   1E = ',F10.0,' CU FT'/)
    AAVOM=VOL-VMB-TANKVL+DHV
    R1=VMB/ENCVOL
    R2=TANKVL/ENCVOL
    R3=AAVOM/ENCVOL
    WRITE(5,124)VMB,R1,TANKVL,R2,AAVOM,R3
124 FORMAT(/,T26,'VOLUME(CU FT)      VOL/ENCVOL'//' MACHINERY ROOM',T28
   1,F10.0,F15.3/' TANKAGE',T28,F10.0,F15.3/' ARRANGEMENTS',T28,F10.0,
   2F15.3/)
    AR=AVAA+DHAA
    WRITE(5,125) AR,AVAA,DHAA
125 FORMAT(/' TOTAL ARRANGEMENTS AREA = ',F8.0/' HULL ARRANGEMENTS ARE
   1A = ',F8.0/' DECKHOUSE ARRANGEMENTS AREA = ',F8.0/)
    WRITE(5,126)
126 FORMAT(' ',T30,'AREA(SQ FT)  AREA/TOT AREA'/)
    R4=ODA/AR
    R5=XMFDA/AR
    R6=CSDA/AR
    R7=OSRDA/AR
    R8=OHDA/AR
    WRITE(5,127)ODA,R4,XMFDA,R5,CSDA,R6,OSRDA,R7,OHDA,R8
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127 FORMAT(' OFFICE SPACE',T30,F10.0,F13.3,/' MESSING FACILITIES',T30,      OUTP0181
   1F10.0,F13.3/' CREW SPECIAL',T30,F10.0,F13.3/' OFFICER S.R.',T30,         OUTP0182
   2F10.0,F13.3/' OFFICER SANITARY',T30,F10.0,F13.3)                         OUTP0183
    R4=CPODA/AR                                                               OUTP0184
    R5=CPOHDA/AR                                                              OUTP0185
    R6=CBDA/AR                                                                OUTP0186
    R7=CHDA/AR                                                                OUTP0187
    R8=CODA/AR                                                                OUTP0188
    WRITE(5,128)CPODA,R4,CPOHDA,R5,CBDA,R6,CHDA,R7,CODA,R8                    OUTP0189
128 FORMAT(' CPO S.R.',T30,F10.0,F13.3/' CPO SANITARY',T30,F10.0,F13.3       OUTP0190
   1/' CREW BERTHING',T30,F10.0,F13.3/' CREW SANITARY',T30,F10.0,F13.3       OUTP0191
   2/' C.O. S.R.,CABIN & PANTRY',T30,F10.0,F13.3)                            OUTP0192
    R4=CSTDA/AR                                                               OUTP0193
    R5=OSDA/AR                                                                OUTP0194
    R6=WDA/AR                                                                 OUTP0195
    R7=RLDA/AR                                                                OUTP0196
    R8=CLDA/AR                                                                OUTP0197
    WRITE(5,129)CSTDA,R4,OSDA,R5,WDA,R6,RLDA,R7,CLDA,R8                       OUTP0198
129 FORMAT(' COMMISSARY STORES',T30,F10.0,F13.3/' OTHER STORES',T30,         OUTP0199
   1F10.0,F13.3/' WORKSHOPS',T30,F10.0,F13.3/' REPAIR LOCKERS',T30,          OUTP0200
   2F10.0,F13.3/' CHAIN LOCKER',T30,F10.0,F13.3)                             OUTP0201
    R4=UTDA/AR                                                                OUTP0202
    R5=SGDA/AR                                                                OUTP0203
    R6=ACDA/AR                                                                OUTP0204
    R7=XICDA/AR                                                               OUTP0205
    R8=AMDA/AR                                                                OUTP0206
    R9=PHDA/AR                                                                OUTP0207
    PDA=.0826*AR                                                              OUTP0208
    R10=PDA/AR                                                                OUTP0209
    WRITE(5,130)UTDA,R4,SGDA,R5,ACDA,R6,XICDA,R7,AMDA,R8,PHDA,R9,PDA          OUTP0210
   1,R10                                                                      OUTP0211
130 FORMAT(' UPTAKES',T30,F10.0,F13.3/' STEERING GEAR & WINDLASS',T30,       OUTP0212
   1F10.0,F13.3/' A/C & FAN SPACES',T30,F10.0,F13.3/' I.C. SPACES',T30       OUTP0213
   2,F10.0,F13.3/' AUX MACHINERY SPACES',T30,F10.0,F13.3/' PILOT HOUSE       OUTP0214
   3,CHARTROOM & CIC',T30,F10.0,F13.3/' PASSAGES',T30,F10.0,F13.3)           OUTP0215
    ARE=AREADH+AREAHL                                                         OUTP0216
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      R1=ARE/AR                                                         OUTP0217
      HABSPC=XMFDA+CSDA+OSRDA+OHDA+CPODA+CPOHDA+CBDA+CHDA+CCDA          OUTP0218
      EXAR=AR-HABSPC-CDA-CSTDA-OSDA-WDA-RLDA-CLDA-UTDA-SGDA-ACDA-XICDA  OUTP0219
     1-AMDA-PHDA-PDA-ARE                                                OUTP0220
      R2=EXAR/AR                                                        OUTP0221
      WRITE(5,131)ARE,R1,EXAR,R2                                        OUTP0222
  131 FORMAT(' INPUT AREA',T30,F10.0,F13.3/' EXCESS AREA',T30,F10.0,F13.OUTP0223
     13/)                                                               OUTP0224
      WRITE(5,132)                                                      OUTP0225
  132 FORMAT(/' CREW SPECIAL INCLUDES SICKBAY,BARBERSHOP,MOVIE LOCKER, LOUTP0226
     1AUNDRY,AND SHIPS STORE'////)                                      OUTP0227
      HABSPC=HABSPC*8.5                                                 OUTP0228
      COEF1=HABSPC/(NOFF+NCPO+NENL)                                     OUTP0229
      COEF2=WTG2/SHPM                                                   OUTP0230
      COEF3=VMB/SHPM                                                    OUTP0231
      COEF4=WTG1/ENCVOL                                                 OUTP0232
      COEF5=WFULLD/ENCVOL                                               OUTP0233
      COEF6=WLSHIP/ENCVOL                                               OUTP0234
      COEF7=CSTG4/TOTCST                                                OUTP0235
      COEF8=CSTG7/TOTCST                                                OUTP0236
      COEF9=CFULLD/DAVG                                                 OUTP0237
      WRITE(5,133)COEF1,COEF2,COEF3,COEF4,COEF5,COEF6,COEF7,COEF8,COEF9 OUTP0238
  133 FORMAT(' HAB VOL/MAN = ',F10.1,' CUFT/MAN'/' GR2WT/HP = ',F6.4,   OUTP0239
     1' TONS/HP'/' MACH ROOM VOL/HP = ',F7.4,' CUFT/HP'/' GR1WT/ENCVOL = OUTP0240
     2 ',F7.5,' TONS/CUFT'/' WFULLD/ENCVOL = ',F7.5,' TONS/CUFT'/' WLSHIOUTP0241
     3P/ENCVOL = ',F7.5,' TONS/CUFT'/' GR4COST/TOTCOST = ',F6.3/' GR7COSOUTP0242
     4T/TOTCOST = ',F6.3/' VCG/DAVG = ',F6.3///)                        OUTP0243
      RETURN                                                            OUTP0244
      END                                                               OUTP0245
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APPENDIX D

C_r ARRAY

.21	.21	.21	.21	.21	.29	.60	1.15	1.77	2.19	2.38	2.40	2.38	2.30	2.20	2.10
.20	.20	.20	.20	.20	.25	.49	.97	1.55	1.94	2.13	2.20	2.18	2.11	2.03	1.92
.20	.20	.21	.21	.22	.26	.46	.68	1.38	1.73	1.91	2.00	2.00	1.98	1.91	1.86
.22	.22	.22	.22	.22	.26	.37	.75	1.20	1.57	1.8	1.98	1.89	1.85	1.79	1.70
.22	.22	.22	.22	.24	.30	.40	.71	1.12	1.47	1.68	1.75	1.77	1.73	1.68	1.60
.22	.22	.22	.22	.29	.38	.41	.65	1.06	1.43	1.63	1.71	1.72	1.70	1.66	1.59
.23	.23	.23	.25	.32	.45	.48	.65	1.03	1.37	1.57	1.66	1.69	1.68	1.62	1.56
.23	.23	.23	.24	.38	.54	.59	.73	1.07	1.37	1.54	1.64	1.67	1.66	1.60	1.53
.23	.23	.23	.27	.43	.70	.74	.80	1.10	1.38	1.54	1.63	1.68	1.67	1.60	1.52
.24	.24	.24	.30	.50	.82	.88	.88	1.15	1.40	1.56	1.63	1.66	1.63	1.60	1.52
.23	.23	.23	.33	.53	.94	1.05	.98	1.19	1.41	1.55	1.63	1.67	1.65	1.60	1.55
.24	.24	.24	.40	.63	1.11	1.21	1.13	1.28	1.43	1.57	1.63	1.65	1.65	1.60	1.56
.25	.25	.26	.35	.41	.47	1.03	2.23	3.73	4.84	5.40	5.53	5.51	5.39	5.07	4.53
.25	.27	.28	.31	.38	.43	.89	1.90	3.29	4.43	5.05	5.25	5.26	5.12	4.83	4.37
.26	.26	.27	.30	.37	.42	.82	1.74	3.00	4.16	4.80	5.02	5.05	4.90	4.60	4.22
.28	.28	.28	.30	.40	.47	.73	1.54	2.71	3.84	4.55	4.80	4.80	4.68	4.40	4.10
.28	.28	.28	.30	.45	.60	.78	1.45	2.55	3.65	4.33	4.58	4.60	4.48	4.24	3.92
.28	.28	.28	.32	.51	.77	.88	1.40	2.45	3.48	4.12	4.38	4.39	4.30	4.10	3.85
.28	.28	.28	.37	.59	1.00	1.03	1.41	2.34	3.33	3.90	4.17	4.20	4.13	3.95	3.80
.28	.28	.28	.40	.68	1.23	1.20	1.54	2.38	3.28	3.81	4.04	4.10	4.02	3.86	3.62
.30	.30	.30	.43	.77	1.48	1.49	1.70	2.41	3.19	3.73	3.97	3.99	3.95	3.81	3.60
.28	.29	.32	.51	.89	1.72	1.83	1.89	2.46	3.23	3.69	3.90	3.95	3.90	3.79	3.64
.28	.28	.32	.60	.98	1.97	2.10	2.07	2.52	3.24	3.68	3.87	3.92	3.89	3.78	3.61
.30	.30	.37	.70	1.11	2.22	2.44	2.28	2.64	3.30	3.68	3.87	3.93	3.90	3.77	3.60
.25	.25	.25	.27	.28	.34	.66	1.20	1.73	2.18	2.40	2.45	2.44	2.39	2.30	2.17
.25	.25	.25	.32	.38	.42	.69	1.10	1.60	2.06	2.28	2.35	2.32	2.25	2.17	2.11
.26	.26	.27	.39	.46	.48	.66	1.02	1.46	1.94	2.13	2.17	2.17	2.13	2.08	2.00
.27	.27	.27	.40	.51	.51	.69	.97	1.38	1.83	2.03	2.10	2.09	2.04	1.96	1.93
.28	.28	.28	.42	.57	.62	.67	.88	1.32	1.71	1.90	1.96	1.97	1.95	1.90	1.86
.30	.30	.30	.43	.58	.68	.71	.89	1.29	1.63	1.81	1.90	1.92	1.90	1.86	1.80
.30	.30	.31	.45	.59	.70	.76	.90	1.23	1.58	1.77	1.83	1.87	1.85	1.80	1.73
.30	.31	.32	.42	.60	.77	.81	.90	1.20	1.54	1.72	1.79	1.80	1.80	1.74	1.70
.33	.33	.33	.40	.62	.85	.90	.95	1.19	1.50	1.70	1.75	1.76	1.74	1.70	1.65
.35	.35	.36	.40	.63	.90	1.00	1.02	1.25	1.53	1.67	1.75	1.77	1.76	1.70	1.63
.34	.34	.35	.40	.64	1.05	1.17	1.12	1.25	1.53	1.69	1.74	1.76	1.75	1.70	1.62
.35	.35	.36	.40	.65	1.20	1.37	1.22	1.25	1.53	1.68	1.74	1.76	1.75	1.70	1.61

.29	.30	.32	.50	.57	.60	1.13	2.19	3.60	4.90	5.56	5.80	5.76	5.57	5.25	5.05
.30	.30	.31	.51	.62	.60	1.04	1.93	3.29	4.57	5.31	5.50	5.50	5.40	5.20	4.80
.33	.33	.33	.52	.66	.66	.97	1.75	3.06	4.27	5.00	5.30	5.30	5.25	5.10	4.90
.32	.32	.33	.52	.68	.71	.96	1.61	2.80	4.04	4.72	5.00	5.00	5.00	4.90	4.70
.34	.34	.34	.54	.73	.82	1.00	1.60	2.68	3.80	4.42	4.71	4.80	4.77	4.64	4.40
.34	.34	.37	.55	.78	.98	1.15	1.65	2.57	3.62	4.26	4.40	4.50	4.50	4.40	4.20
.37	.38	.40	.57	.83	1.17	1.34	1.70	2.55	3.52	4.17	4.45	4.50	4.55	4.50	4.30
.38	.38	.40	.58	.88	1.35	1.60	1.85	2.55	3.46	4.08	4.34	4.42	4.42	4.35	4.20
.38	.38	.41	.59	.94	1.60	1.85	2.02	2.54	3.40	4.05	4.41	4.55	4.50	4.30	4.00
.40	.40	.48	.63	1.02	1.82	2.07	2.21	2.70	3.44	4.03	4.27	4.35	4.25	4.10	3.80
.40	.40	.48	.70	1.11	2.07	2.40	2.45	2.80	3.48	4.04	4.28	4.35	4.30	4.10	3.80
.41	.41	.54	.80	1.24	2.30	2.70	2.71	2.98	3.60	4.05	4.26	4.32	4.30	4.10	3.80
.30	.30	.30	.41	.48	.47	.64	1.20	1.87	2.35	2.68	2.80	2.80	2.76	2.70	2.60
.33	.33	.33	.42	.48	.47	.65	1.09	1.63	2.13	2.45	2.59	2.60	2.58	2.50	2.40
.35	.35	.35	.43	.46	.44	.59	.93	1.48	2.01	2.26	2.37	2.39	2.37	2.31	2.24
.37	.37	.37	.41	.47	.45	.58	.87	1.34	1.82	2.06	2.17	2.20	2.20	2.13	2.06
.40	.40	.40	.43	.48	.49	.59	.82	1.24	1.65	1.90	2.00	2.06	2.05	2.00	1.91
.40	.40	.40	.42	.48	.54	.63	.83	1.23	1.60	1.80	1.93	1.97	1.97	1.91	1.78
.42	.42	.42	.45	.52	.61	.73	.81	1.18	1.53	1.74	1.87	1.93	1.90	1.85	1.73
.42	.42	.42	.44	.54	.69	.81	.90	1.16	1.53	1.77	1.89	1.90	1.89	1.80	1.70
.45	.45	.45	.50	.58	.80	.93	1.00	1.18	1.52	1.73	1.83	1.88	1.85	1.78	1.69
.47	.47	.47	.56	.67	.90	1.05	1.09	1.23	1.53	1.74	1.85	1.88	1.84	1.77	1.67
.48	.48	.48	.62	.70	1.00	1.20	1.20	1.30	1.52	1.71	1.85	1.87	1.82	1.74	1.69
.49	.49	.49	.68	.73	1.10	1.34	1.33	1.37	1.52	1.71	1.84	1.87	1.80	1.72	1.70
.35	.35	.40	.53	.67	.65	1.13	2.30	3.72	5.00	5.95	6.40	6.50	6.40	6.10	5.50
.38	.38	.42	.54	.65	.63	1.00	1.95	3.40	4.67	5.50	5.80	5.90	5.80	5.50	5.10
.41	.41	.43	.53	.60	.63	.89	1.78	3.10	4.33	5.10	5.35	5.40	5.30	5.10	4.90
.43	.43	.45	.53	.64	.70	.91	1.70	2.90	4.07	4.79	5.00	5.10	5.10	4.90	4.70
.45	.45	.45	.53	.68	.81	.97	1.62	2.73	3.87	4.60	4.95	5.10	5.00	4.90	4.60
.45	.45	.47	.53	.72	.91	1.15	1.59	2.62	3.75	4.48	4.90	5.00	5.00	4.90	4.50
.48	.49	.50	.56	.78	1.10	1.35	1.78	2.64	3.70	4.40	4.74	4.80	4.75	4.60	4.25
.48	.48	.50	.56	.84	1.30	1.60	1.92	2.63	3.65	4.34	4.65	4.70	4.58	4.40	4.10
.52	.52	.53	.63	.93	1.53	1.85	2.13	2.77	3.63	4.29	4.61	4.70	4.55	4.35	4.00
.53	.54	.56	.70	1.01	1.78	2.10	2.32	2.85	3.61	4.24	4.55	4.60	4.50	4.25	3.90
.55	.55	.58	.79	1.16	2.05	2.40	2.57	3.00	3.67	4.23	4.53	4.55	4.40	4.10	3.80
.58	.58	.66	.90	1.30	2.30	2.73	2.83	3.20	3.70	4.22	4.50	4.45	4.25	4.00	3.70

.31	.31	.33	.50	.57	.64	1.50	3.40	5.65
.31	.31	.34	.43	.52	.60	1.20	1.80	5.10
.30	.30	.32	.38	.48	.60	1.12	2.60	4.60
.33	.33	.34	.39	.52	.78	1.07	2.23	4.17
.33	.33	.35	.40	.58	.86	1.13	2.10	3.90
.34	.34	.34	.42	.67	1.14	1.30	2.05	3.83
.34	.34	.35	.46	.79	1.45	1.55	2.10	3.67
.34	.34	.37	.50	.89	1.76	1.84	2.26	3.65
.34	.34	.38	.57	1.00	2.09	2.23	2.50	3.68
.33	.33	.40	.65	1.15	2.43	2.69	2.82	3.80
.34	.34	.41	.74	1.29	2.75	3.18	3.18	3.90
.35	.36	.47	.85	1.45	3.12	3.76	3.63	4.10
.35	.35	.40	.60	.72	.85	2.00	4.70	7.70
.35	.36	.39	.50	.60	.74	1.54	3.65	7.00
.35	.35	.38	.46	.57	.73	1.37	3.30	6.30
.38	.38	.40	.47	.61	.83	1.37	2.85	5.70
.38	.38	.40	.48	.70	1.10	1.49	2.72	4.32
.38	.38	.40	.51	.83	1.45	1.70	2.65	5.20
.38	.38	.42	.55	.97	1.80	2.00	2.70	4.00
.39	.39	.43	.62	1.10	2.18	2.43	2.97	5.10
.40	.40	.46	.69	1.20	2.62	2.95	3.30	5.00
.40	.40	.48	.77	1.40	3.07	3.56	3.73	5.15
.40	.40	.50	.86	1.55	3.50	4.23	4.23	5.30
.40	.42	.57	.98	1.71	4.00	5.03	4.89	5.60
.40	.41	.48	.70	.88	1.10	2.60	6.00	9.70
.42	.42	.46	.60	.72	.90	1.90	4.45	9.00
.42	.42	.43	.52	.67	.83	1.60	4.15	8.10
.42	.42	.45	.52	.70	.94	1.57	3.80	7.20
.43	.43	.46	.55	.81	1.26	1.73	3.40	6.80
.44	.44	.48	.58	.95	1.70	2.00	3.45	6.50
.45	.45	.50	.63	1.10	2.11	2.45	3.33	6.35
.45	.45	.50	.70	1.26	2.63	3.05	3.64	6.15
.47	.47	.53	.78	1.40	3.10	3.70	4.10	5.30
.46	.48	.57	.86	1.58	3.70	4.46	4.64	6.40
.45	.46	.58	.95	1.75	4.20	5.33	5.28	6.80
.47	.49	.68	1.08	1.93	4.90	6.30	6.00	7.05

.36	.36	.37	.66	.78	.86	1.60	3.40	6.10
.35	.35	.38	.62	.76	.82	1.40	2.90	5.10
.39	.38	.39	.60	.77	.81	1.25	2.55	4.75
.38	.38	.40	.60	.78	.84	1.23	2.45	4.45
.40	.40	.42	.60	.82	1.00	1.30	2.34	4.20
.40	.40	.43	.62	.89	1.25	1.50	2.36	3.97
.42	.42	.44	.64	.99	1.52	1.80	2.50	3.83
.44	.44	.47	.68	1.08	1.83	2.20	2.70	3.90
.43	.43	.49	.72	1.20	2.17	2.63	3.01	3.98
.45	.46	.55	.79	1.35	2.50	3.05	3.34	4.20
.46	.46	.58	.94	1.50	2.85	3.54	3.75	4.45
.48	.49	.67	1.07	1.65	3.24	4.04	4.18	4.80
.41	.41	.45	.76	.95	1.07	2.07	4.75	9.20
.42	.42	.45	.72	.86	.98	1.80	3.95	7.00
.44	.44	.47	.68	.83	.96	1.58	3.50	6.50
.43	.43	.47	.65	.82	.97	1.52	3.13	6.20
.44	.45	.48	.64	.89	1.15	1.58	3.00	5.54
.47	.47	.50	.66	.95	1.48	1.83	2.94	5.20
.47	.47	.52	.70	1.05	1.83	2.36	3.12	5.03
.50	.50	.54	.73	1.18	2.20	2.77	3.44	5.32
.50	.51	.58	.80	1.37	2.67	3.30	3.80	5.40
.53	.53	.62	.89	1.50	3.10	3.90	4.27	5.70
.53	.53	.68	1.04	1.73	3.55	4.62	4.90	6.17
.55	.56	.78	1.22	1.90	4.00	5.30	5.60	6.60
.47	.47	.53	.87	1.10	1.29	2.73	6.10	12.00
.48	.48	.52	.81	.97	1.17	2.25	4.90	9.00
.50	.50	.54	.75	.90	1.08	1.90	4.50	8.20
.52	.52	.54	.72	.87	1.07	1.80	3.80	7.50
.52	.52	.56	.70	.93	1.25	1.87	3.60	6.70
.53	.53	.57	.73	1.01	1.69	2.21	3.45	6.25
.55	.55	.58	.76	1.13	2.13	2.74	3.65	6.10
.53	.53	.62	.80	1.28	2.58	3.32	4.04	6.75
.56	.57	.66	.87	1.46	3.09	3.94	4.55	6.80
.58	.58	.73	.96	1.63	3.60	4.74	5.17	7.20
.58	.58	.77	1.10	1.84	4.17	5.74	5.95	7.90
.60	.62	.88	1.31	2.07	4.70	6.45	7.05	8.40

.42	.42	.49	.70	.88	.95	1.68	3.43	6.00
.46	.46	.50	.67	.81	.88	1.42	2.91	5.40
.46	.46	.51	.66	.77	.85	1.30	2.65	4.95
.50	.50	.54	.67	.77	.96	1.28	2.44	4.45
.50	.50	.53	.64	.81	1.08	1.38	2.33	4.10
.52	.52	.54	.63	.88	1.24	1.60	2.45	4.05
.53	.55	.57	.65	.97	1.47	1.87	2.53	4.10
.53	.53	.58	.66	1.08	1.75	2.25	2.90	4.15
.58	.58	.62	.73	1.24	2.10	2.65	3.17	4.30
.60	.60	.67	.84	1.31	2.48	3.10	3.53	4.50
.62	.62	.68	.95	1.48	2.86	3.60	3.96	4.73
.63	.63	.77	1.10	1.64	3.27	4.13	4.38	5.07
.48	.50	.56	.84	1.09	1.28	2.20	4.63	8.20
.52	.52	.60	.82	.99	1.16	1.90	4.10	7.10
.55	.55	.59	.78	.92	1.10	1.72	3.61	6.50
.55	.55	.61	.80	.92	1.18	1.68	3.30	5.95
.57	.57	.62	.73	.96	1.33	1.77	3.10	5.50
.58	.58	.62	.73	1.01	1.51	2.05	3.13	5.30
.62	.60	.65	.76	1.11	1.76	2.40	3.30	5.20
.62	.62	.68	.78	1.25	2.10	2.80	3.60	5.30
.65	.65	.73	.85	1.40	2.50	3.30	3.98	5.55
.67	.67	.76	.96	1.58	2.95	3.83	4.44	5.80
.67	.67	.80	1.09	1.75	3.45	4.43	5.00	6.15
.72	.71	.85	1.23	1.94	3.90	5.15	5.63	6.54
.55	.56	.65	1.00	1.32	1.60	2.86	5.90	10.40
.58	.58	.65	.94	1.16	1.35	2.48	5.15	8.80
.61	.60	.67	.90	1.07	1.30	2.20	4.50	7.90
.62	.62	.70	.87	1.05	1.36	2.10	4.05	7.40
.64	.64	.70	.83	1.10	1.53	2.18	3.80	6.90
.64	.64	.73	.81	1.15	1.79	2.43	3.80	6.50
.68	.70	.75	.87	1.25	2.13	2.85	3.90	6.30
.68	.68	.77	.87	1.37	2.55	3.35	4.27	6.20
.70	.72	.82	.98	1.57	3.05	3.98	4.80	6.50
.73	.73	.84	1.09	1.77	3.60	4.65	5.30	6.80
.74	.75	.90	1.20	2.00	4.10	5.35	5.90	7.20
.77	.77	.95	1.34	2.20	4.30	5.85	6.40	8.6

.44	.45	.53	.82	1.08	1.31
.46	.47	.51	.67	.86	1.04
.47	.47	.48	.59	.77	.94
.48	.48	.50	.60	.80	1.03
.50	.49	.51	.63	.90	1.37
.50	.50	.53	.65	1.07	1.87
.50	.50	.55	.70	1.23	2.43
.50	.50	.57	.76	1.40	3.06
.52	.52	.60	.83	1.55	3.60
.52	.53	.65	.93	1.74	4.15
.52	.53	.68	1.03	1.93	4.90
.52	.56	.76	1.18	2.10	4.8C
.52	.52	.61	1.05	1.32	1.57
.53	.54	.63	.94	1.10	1.32
.55	.56	.62	.86	1.02	1.20
.57	.57	.63	.82	.93	1.20
.58	.58	.64	.80	1.00	1.43
.58	.60	.65	.83	1.08	1.87
.60	.60	.68	.84	1.22	2.40
.62	.62	.70	.87	1.37	2.91
.62	.62	.75	.94	1.55	3.50
.64	.66	.80	1.03	1.75	4.10
.67	.67	.85	1.17	1.93	4.75
.67	.71	.96	1.38	2.23	4.90
.62	.64	.75	1.15	1.56	1.93
.65	.67	.75	1.10	1.35	1.59
.68	.69	.75	1.01	1.22	1.46
.70	.70	.78	.98	1.16	1.51
.72	.72	.79	.94	1.19	1.70
.72	.72	.81	.94	1.28	2.00
.74	.76	.83	.96	1.40	2.42
.77	.77	.87	1.00	1.56	3.00
.78	.78	.91	1.10	1.75	3.5C
.80	.80	.97	1.22	1.94	4.30
.80	.82	1.00	1.32	2.14	4.90
.82	.83	1.05	1.47	2.40	5.10

APPENDIX E

HULL GROUP WEIGHT CLASSIFICATION OF 1965

NAVSHIPS HULL GROUP WEIGHT CLASSIFICATION OF 1965

Group 1 - Hull Structure

100 - Shell Plating and Planking
101 - Longitudinal and Transverse Framing
102 - Inner Bottom
103 - Platforms and Flats Below Lowermost Continuous Deck
104 - Fourth and Lower Continuous Decks
105 - Third Deck
106 - Second Deck
107 - Main Deck and Hangar Deck
108 - Forecastle and Poop Decks
109 - Gallery Deck
110 - Flight Deck, Landing Platforms, Special Purpose Decks above Weather Deck
111 - Superstructure
112 - Foundations for Propulsion Plant Machinery
113 - Foundations for Auxiliaries and Other Equipment
114 - Structural Bulkheads
115 - Trunks and Enclosures
116 - Structural Sponsons
117 - Armor
118 - Aircraft Fuel Saddle Tank Structure
119 - Structural Castings, Forgings and Equivalent Weldments
120 - Sea Chests
121 - Ballast and Buoyancy Units, Fixed or Fluid
122 - Doors and Closures, Special Purpose
123 - Doors, Hatches, Manholes and Scuttles - Nonballistic
124 - Doors, Hatches, Manholes and Scuttles - Ballistic
125 - Kingposts and Support Frames
127 - Sonar Dome
128 - Masts, Towers, Tetrapods, and Service Platforms
150 - Welding, Riveting, and Fastenings
151 - Free Flooding Liquids

Group 2 - Propulsion

200 - Boilers and Energy Converters (Non-Nuclear)
201 - Propulsion Units
202 - Main Condensers and Air Ejectors
203 - Shafting, Bearings, and Propellers
204 - Combustion Air Supply System
205 - Uptakes (Smoke Pipes)
206 - Propulsion Control Equipment (Non-Nuclear)
207 - Main Steam System
208 - Feedwater and Condensate System
209 - Circulating and Cooling Water Systems
210 - Fuel Oil Service System
211 - Lubricating Oil System
212 - Nuclear Steam Generators
213 - Reactors
214 - Reactor Coolant System
215 - Reactor Coolant Service Systems
216 - Reactor Plant Auxiliary Systems
217 - Nuclear Power Control and Instrumentation
218 - Radiation Shielding (Primary)
219 - Radiation Shielding (Secondary)
250 - Propulsion Repair Parts
251 - Propulsion Operating Fluids

Group 3 - Electric Plant

300 - Electric Power Generation
301 - Power Distribution Switchboards
302 - Power Distribution System (Cable)
303 - Lighting System (Distribution and Fixtures)
350 - Electric Plant Repair Parts
351 - Electric Power Generator Fluids

Group 4 - Communication and Control

400 - Navigation Equipment (Non-Electronic)
401 - Interior Communication Systems and Equipment
402 - Gun Fire Control System
403 - Countermeasure Systems (Non-Electronic)
404 - Electronic Countermeasure Systems (ECM)
405 - Missile Fire Control Systems
406 - ASW, Torpedo Fire Control Systems (Surface Ships)
407 - Torpedo Fire Control System (Submarines)
408 - Radar Systems
409 - Radio Communication Systems
410 - Electronic Navigation Systems
411 - Space Vehicle Electronic Tracking Systems
412 - Sonar Systems
413 - Electronic Tactical Data System
450 - Communication and Control Repair Parts
451 - Communication and Control Operating Fluids

Group 5 - Auxiliary Systems

500 - Heating System
501 - Ventilation System
502 - Air Conditioning System
503 - Refrigerating Spaces, Plant, and Equipment
504 - Gasoline, HEAF, All Liquid Cargo Piping, Oxygen, Nitrogen, and Aviation Lubricating Oil Systems
505 - Plumbing Installations
506 - Firemain, Flushing, Sprinkler, Washdown, and Salt Water Service Systems
507 - Fire Extinguishing Systems
508 - Drainage, Ballast, Trimming, Heeling, and Stabilizer Tank Systems
509 - Fresh Water System
510 - Scuppers and Deck Drains
511 - Fuel and Diesel Oil Filling, Venting, Stowage and Transfer Systems
512 - Tank Heating Systems
513 - Compressed Air System
514 - Auxiliary Steam, Exhaust Steam, and Steam Drains
515 - Buoyancy Control System
516 - Miscellaneous Piping Systems
517 - Distilling Plant
518 - Steering Systems
519 - Rudders
520 - Mooring, Towing, Anchor and Aircraft Handling Systems and Deck Machinery
521 - Elevators, Moving Stairways, Stores Strikedown, and Stores Handling Equipment
522 - Operating Gear for Retracting and Elevating Units
523 - Aircraft Elevators
524 - Aircraft Arresting Gear, Barriers, and Barricades
525 - Catapults and Jet Blast Deflectors
527 - Diving Planes and Stabilizing Fins
528 - Replenishment at Sea and Cargo Handling
550 - Auxiliary Systems Repair Parts
551 - Auxiliary Systems Operating Fluids, Gases, and Stabilizer Fluids

Group 6 - Outfit and Furnishings

600 - Hull Fittings
601 - Boats, Boat Stowage, and Handling
602 - Rigging and Canvas
603 - Ladders and Gratings
604 - Nonstructural Bulkheads and Nonstructural Doors
605 - Painting
606 - Deck Covering
607 - Hull Insulation
608 - Storerooms, Stowages and Lockers
609 - Equipment for Utility Spaces
610 - Equipment for Workshops, Laboratories, and Test Areas
611 - Equipment for Galley, Pantry, Scullery and Commissary
612 - Furnishings for Living Spaces
613 - Furnishings: Offices, Control Centers, Machinery Spaces
614 - Furnishings for Medical, Dental, and Pharmaceutical
615 - Radiation Shielding for Nuclear Support Facilities
650 - Outfit and Furnishings Repair Parts
651 - Outfit and Furnishings Operating Fluids

Group 7 - Armament

700 - Guns and Gun Mounts
701 - Ammunition Handling Systems
702 - Ammunition Stowage
703 - Special Weapons, Handling and Stowage
704 - Rocket and Missile Launching Devices (Surface to Air, Surface to Surface, and Sub-Surface)
705 - Rocket and Missile Launching Devices (Antisubmarine Warfare)
706 - Rocket, Missile, and Components Handling Systems
707 - Rocket, Missile, and Components Stowage
708 - Torpedo Tubes
709 - Torpedo Handling and Stowage
710 - Mine Handling Systems and Stowage
711 - Small Arms and Pyrotechnic Stowage
712 - Air-Launched Weapons Handling Systems
713 - Air-Launched Weapons Stowage
720 - Cargo Munition Stowage
745 - General Arrangement - Armament Drawings
750 - Armament Repair Parts
751 - Armament Operating Fluids